2

AD-A234 395

Fueling Operational Maneuver

A Monograph
by

Major William J. Bayles
Corps of Engineers

School of Advanced Military Studies
United States Army Command and General Staff College
Fort Leavenworth, Kansas

Second Term AY 89/90

Approved for Public Release; Distribution is Unlimited

91 4

ICLASSIFIED
RITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

1b. RESTRICTIVE MARKINGS

SECURITY CLASSIFICATION AUTHORITY

3. DISTRIBUTION/AVAILABILITY OF REPORT
Approved for public release;
Distribution unlimited

DECLASSIFICATION/DOWNGRADING SCHEDULE

ERFORMING ORGANIZATION REPORT NUMBER(S)

5. MONITORING ORGANIZATION REPORT NUMBER(S)

NAME OF PERFORMING ORGANIZATION
School of Advanced Military Studies, USACGSC

6b. OFFICE SYMBOL (If applicable)
ATZL-SWV

7a. NAME OF MONITORING ORGANIZATION

ADDRESS (City, State, and ZIP Code)
Fort Leavenworth, Kansas 66027-6900

7b. ADDRESS (City, State, and ZIP Code)

NAME OF FUNDING/SPONSORING ORGANIZATION

8b. OFFICE SYMBOL (If applicable)

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

ADDRESS (City, State, and ZIP Code)

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.

1. TITLE (Include Security Classification)
Fueling Operational Maneuver (U)

2. PERSONAL AUTHOR(S)
Major William J. Bayles, USA

3a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Monograph	FROM ____ TO ____	90/5/29	39

6. SUPPLEMENTARY NOTATION

7. COSATI CODES		
FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
POL Mobility fuel
Transportation Pipelines
Inland waterways Rail transport Highway transport

9. ABSTRACT (Continue on reverse if necessary and identify by block number)

Bulk petroleum products are vital to every facet of U.S. Army operations. Even the smallest and "lightest" units rely on the Army's Combat Service Support system to provide them with the fuels needed for ground mobility and CSS operations. What means will logisticians use to transport the needed fuel to the fighting units of a corps in an immature theater?

Fuel transport methods available to the planner may include pipelines, railway tank cars, inland waterways, motor trucks and combinations of these modes. Each method's characteristics and capacities indicate its suitability in a given area of operations. This monograph examines the characteristics and capacities in each transport mode in terms of criteria based on the sustainment imperatives of FM 100-5.

(CONTINUED ON THE BACK)

0. DISTRIBUTION/AVAILABILITY OF ABSTRACT
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION
UNCLASSIFIED

2a. NAME OF RESPONSIBLE INDIVIDUAL	22b TELEPHONE (Include Area Code)	22c. OFFICE SYMBOL
MAJ William J. Bayles	(913) 684-3437	ATZL-SWV

D Form 1473, JUN 86 *Previous editions are obsolete.* SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

Block 19. Continuation

The mongraph relies heavily on classical military theory. Definitions of modern terms are explained in their theoretical context. The sustainment imperatives--anticipation, integration, continuity, responsiveness, and improvisation--are derived from classical theory. These are then used to form six major categories of criteria to examine each transportation mode.

The monograph concludes that current army doctrine describes a workable fuel transport system given the capacities of the various transport modes and today's technology. The concept of using pipeline transport as the mainstay of a mixed mode system that is phased into the theater best meets sustainment imperatives. The analysis also suggests a sixth sustainment imperative, minimizing overhead, as a consideration for the operational logistician.

School of Advanced Military Studies
Monograph Approval

Name of Student: Major William J. Bayles
Title of Monograph: Fueling Operational Maneuver

Approved by:

Dennis K. Hill ________________ Monograph Director
Lieutenant Colonel Dennis K. Hill, MS

William H. Janes ________________ Director, School of
Colonel William H. Janes, MA Advanced Military Studies

Philip J. Brookes ________________ Director, Graduate Degree
Philip J. Brookes, Ph.D. Programs

Accepted this 7th day of June 1990.

A-1

Abstract

Fueling Operational Maneuver
by Major William J. Bayles, U.S. Army, 39 pages.

Bulk petroleum products are vital to every facet of U.S. Army operations. Even the smallest and "lightest" units rely on the Army's Combat Service Support system to provide them with the fuels needed for ground mobility and CSS operations. What means will logisticians use to transport the needed fuel to the fighting units of a corps in an immature theater?

Fuel transport methods available to the planner may include pipelines, railway tank cars, inland waterways, motor trucks and combinations of these modes. Each method's characteristics and capacities indicate its suitability in a given area of operations. This monograph examines the characteristics and capacities of each transport mode in terms of criteria based on the sustainment imperatives of FM 100-5.

The monograph relies heavily on classical military theory. Definitions of modern terms are explained in their theoretical context. The sustainment imperatives--anticipation, integration, continuity, responsiveness, and improvisation--are derived from classical theory. These are then used to form six major categories of criteria to examine each transportation mode.

The monograph concludes that current army doctrine describes a workable fuel transport system given the capacities of the various transport modes and today's technology. The concept of using pipeline transport as the mainstay of a mixed mode system that is phased into the theater best meets the sustainment imperatives. The analysis also suggests a sixth sustainment imperative, minimizing overhead, as a consideration for the operational logistician.

Fueling Operational Maneuver

Introduction

In August 1944, two months after the beginning of the most thoroughly planned military operation in history, United States forces in France faced a crippling shortage of gasoline which brought their operations to a standstill. Although over 25 million gallons of fuel lay in depots in Normandy, the armies pursuing the Germans were 250 miles from these sources. Their problem was one of transportation and distribution, not one of supply.[1] At this juncture, logisticians made a critical decision. All transportation assets, even the trucks from artillery and engineer units were devoted to hauling high priority supplies--mostly gasoline, into the combat zone.[2] One crucial expense of hauling fuel by truck was the temporary abandonment of hauling material for pipeline construction. Was this the proper operational decision? In 1944, the pipeline was considered the most efficient means of transporting bulk liquids and extensive systems were planned for the European Theater. Yet

> faced with a choice between the certainty of long-term savings . . . and the more urgent needs of the moment, the Communications Zone tended to choose the latter and divert truck units to the higher priority forwarding of gasoline, rations, and ammunition.[3]

There were several costs to this decision. First, the long-term savings mentioned by the historian failed to materialize until much later, when priority was once again given to transporting construction materials. Next, a truck convoy system consuming some 300,000 gallons of fuel daily undertook the job of supplying the forward troops.[4] Finally, the First and Third U.S. Armies were forced to exist on daily deliveries and had no opportunity to build up any buffer of fuel supplies because the supply system was insufficient to provide even daily consumption needs.

Did the logisticians of the Communications Zone prolong the war by denying General Patton the means to swiftly defeat the Third Reich? Did they make a conscious decision to assume risk and attempt to improvise a war-winning solution, or as Dr. Ruppenthal suggests did they merely follow the path of least resistance and "tend to choose" this solution?

While the conditions of 1944 France and 1990 contingency operations are somewhat different, today's logisticians weigh tradeoffs similar to those facing their World War II counterparts. To help them make informed decisions they must have tools to weigh the costs and benefits of various means of transporting bulk fuel. While the 1944 decision did not decide the

---

[1] Roland Ruppenthal, *Logistical Support of the Armies, Volume I*, Center of Military History, Washington, 1954, p. 509 and p. 513.
[2] Ibid. p. 508.
[3] Ibid. p. 513.
[4] Ibid. p. 509.

outcome of the war, the success of future U.S. operations may depend on optimal use of the resources at hand.

The dilemma of fuel supply is one of the primary challenges facing operational planners today. Indeed, fuel supply is cited as the major reason preventing extended operations beyond the forward line of own troops (FLOT).[5] Only ammunition rivals fuel in terms of supply tonnage and criticality to mechanized operations.

Motor vehicle fuel is absolutely vital to the fighting forces of the United States. This criticality is recognized by our key doctrinal manual, Field Manual (FM) 100-5, *Operations*. It lists "fueling" as one of the six key sustainment functions, and points out that

> An army's ability to marshal, transport, and distribute large quantities of materiel and to maintain the men and equipment of large units can make the decisive difference between victory and defeat in high- or mid-intensity conflict.[6]

Since the United States is one of the world's largest crude oil producers, the key word in this quote is "transport." In 1988 the United States produced 3 billion barrels of petroleum. By comparison, the largest OPEC producer, Saudi Arabia, pumped approximately 1.5 billion barrels.[7] Thus the U.S. has petroleum, but the key question is whether it can deliver refined products to fighting men and their machines. As a former NATO fuel planner points out, "Crippling fuel shortages in the front lines are more often due not to availability problems per se, but rather due to an inability to deliver fuel to consuming units at the right place and time."[8]

This monograph centers on the basic question: By what means should the Army's theater sustainment structure provide adequate fuel to a corps in an immature theater? The question itself contains ideas open to interpretation or question. First, how big is the corps? Next, what is adequate? These are answered in the appendix, but these answers are not as important as the analysis to be presented.

Succinctly put, the paper examines the characteristics and capacities of four means of transporting bulk fuel at the wholesale level[9]--pipelines, railway tank cars, barges using inland waterways, and highway tank trucks. It aims to provide insights for operational planners and to guide the development of doctrine. It identifies tradeoffs in capacity, overhead, construction time, vulnerability, and suitability of the methods as means to fuel operational maneuver forces. If planners and doctrine writers can balance the tradeoffs of fueling operational maneuver, they have made a major step toward making such maneuver a more viable part of AirLand Battle doctrine.

---

[5]William A. Brinkley, "The Cost Across the FLOT," *Military Review*, pp. 30-41, September 1986.
[6]*Field Manual 100-5, Operations*, Department of the Army, Washington, May 1986, p. 59.
[7]Otto Johnson, ed. *The 1990 Information Please Almanac*, Houghton Mifflin Company, Boston, 1989, p.379.
[8]Tom Cutler, "Myths of Military Oil Supply Vulnerability," *Armed Forces Journal International*, p. 46, July 1989.
[9]For the purposes of this monograph, "wholesale level" will be taken to mean from sea port to COSCOM storage sites.

The analysis is based on several assumptions. This study examines the needs of a contingency corps consisting of an airborne division, an air assault division, a mechanized division, and corresponding corps support command (COSCOM) assets with force structures typical to 1990. The sample force used in the monograph is the hypothetical 21st Corps, based on instructional material from the Command and General Staff College. The listing of units appears in Appendix A. Fuel consumption for these units is based on those planning figures found in FM 101-10-1, *Staff Officer's Field Manual: Organizational, Technical, and Logistical Data Planning Factors.* The study assumes that unlimited quantities of bulk fuel are available at a seaport or pipeline terminal and that it must then be transported 200 kilometers to the combat zone. Finally, host nation support is limited to barge and rail operations only. With these assumptions in mind, we may turn to explaining critical concepts.

Definitions

Readers must understand several definitions used in this monograph. Many concepts in current usage in the military have roots in classical military theory dating to the 18th and 19th centuries. Others are defined by our doctrine.

Logistics, according to U.S. Army doctrine is the "science of planning and carrying out the movement and maintenance of forces..."[10] The theorist Baron Antione Jomini states that it is one of the five branches of the art of war, along with strategy, grand tactics, engineering, and tactics.[11]

> Logistics is the art of moving armies. It comprises the order and details of marches and camps, and of quartering and supplying troops; in a word, it is the execution of strategical and tactical enterprises.[12]

Logistics includes "arranging and superintending the march of trains of baggage, munitions, provisions...providing for successive arrival of convoys of supplies...establishing and organizing lines of operations and supplies..."[13] Thus logistics is both an art and science concerned with movement of armies and their supplies and is inextricably linked to "strategical and tactical enterprises." A subset of logistics is operational sustainment.

Operational sustainment differs from logistics in that it encompasses fewer activities. As defined by U.S. Army doctrine, operational sustainment "comprises those logistical and support activities required to sustain campaigns and major operations within a theater of operations."[14] It is concerned with linking the theater sustaining bases to forward combat service support units whose supported units are in enemy contact. Under this definition, operational sustainment entails wholesale service support and supply activities, as well as long term planning. Operational

[10] *Field Manual 100-16, Support Operations: Echelons Above Corps,* Department of the Army, Washington, April 1985, p. 6-2.
[11] Antoine Henri Jomini, *The Art of War,* Greenwood Press,Westport, Connecticut, 1977, p. 13.
[12] Ibid. p. 69.
[13] Ibid. p. 252.
[14] *FM 100-5*, p. 65.

sustainment is key to any activity undertaken by the force, but its planning is particularly critical if the force conducts operational maneuver.

Definitions of operational maneuver focus on relative movements of enemy and friendly forces. Carl von Clausewitz calls maneuver "...a play of balanced forces whose aim is to bring about favorable conditions for success and then use them to gain advantage over the enemy."[15] Modern definitions echo this theme, with FM 100-5 defining maneuver as "the movement of forces with respect to the enemy to secure or retain positional advantage."[16] At the operational level, maneuver concentrates or disperses friendly forces to seek a decisive impact on the campaign. To accomplish this, large forces may have to be quickly moved to great depths on the battlefield.

Operational movement, on the other hand, has relationship only to the terrain. It is limited to deployments into or within the theater.[17] The commander may need to reposition forces behind the FLOT for future missions. An example of operational movement is large forces moving via various transportation means from ports of debarkation into a relatively distant combat zone. The nature of these moves is administrative and enemy contact is not desired. As defined, operational movement is a subset of what Jomini called "logistics."

Supply routes, lines of operation, communication, and support are similar concepts in that they are pathways for movement and maneuver. These lines are physical areas on the ground, sea, or in the air which may be traversed by friendly forces. Vehicles carrying sustainment packages and fresh units traverse supply routes, while combat forces attack or withdraw along lines of operation. Together, supply routes and lines of operation comprise lines of communication. Lines of support are simply collections of lines of communication.[18] Clausewitz writes, "It follows that war, with its numerous tentacles, prefers to suck nourishment from main roads, populous towns, fertile valleys traversed by broad rivers, and busy coastal areas."[19] Since today's military forces depend upon the transport to such a great degree, infrastructures suitable for lines of communications may define a theater of operations.

The theater of operations is a distinct subset of the entire area where forces are fighting. As Clausewitz states, the theater of operations is "a sector of the total war area which has protected boundaries and so a certain degree of independence." Thus, the theater of operations is not only a portion of the whole theater of war, but a subelement with its own character. Events outside the theater of operations but within the theater of war cause only indirect changes in the theater of operations.[20]

---

[15]Carl von Clausewitz, *On War*, Princeton University Press, Princeton, New Jersey, 1984, p. 541.
[16]*FM 100-5*, p. 12.
[17]TRADOC Pamphlet 11-9, (Draft), "Blueprint of the Battlefield," U.S. Army Training and Doctrine Command, Ft. Monroe, Virginia, 1989, Figure 4-7.
[18]James J. Schneider, "Theoretical Paper Number Three," School of Advanced Military Studies, Ft. Leavenworth, Kansas, 1988, p. 24.
[19]Clausewitz, p. 338.
[20]Clausewitz, p. 280.

Finally, the campaign may be defined as a series of directly related events in a given theater of operations. Usually, these events are of a magnitude that they affect forces across the entire theater of operations.[21] Such a series may be linked by one side maintaining offensive action. On the other hand a series may be related by operations within a given geographic region.

Today's doctrine stresses the need for campaigns to link strategic and operational ends within a theater of operations. Heavy land forces, which are among the means to accomplish operational ends, consume significant amounts of resources. Thus operational commanders searching for ways to achieve their ends must first plan for the sustainment of their means.

Significance of the Study

The problem of moving large quantities of fuel quickly across great distances is one that has recently taken on new importance for the U.S. Army. The reasons for this increased importance are changes in doctrine, equipment, funding, and force structure.

Doctrine, an army's body of officially sanctioned theory, determines how the army operates, fights, and sustains itself. The U.S. Army embraces a doctrine of maneuver warfare that requires large forces to move great distances on the battlefield. These distances dictate that lines of operation and supply coincide resulting in numbers of units trying to use the same infrastructure simultaneously. Conversely, our service support doctrine focuses on support of units in a slow moving or static environment. In the logisticians' view, operational art is tactics on a larger scale.[22]

The equipment necessary to execute our maneuver doctrine consumes fuel on an unprecedented scale. This gives a new magnitude to the fuel supply problem. Current estimates of consumption for a single mechanized division in combat are over 360,000 gallons per day, making it impractical for divisions to carry sufficient resources for multiple days of combat.[23] The recent move to a single fuel, JP-8, for all of the army's equipment mitigates the supply problem somewhat by eliminating the need for duplicate transport and storage systems.[24] The problem remains that transporting such bulk is a major challenge.

In spite of new doctrine and equipment increasing our fuel demand, future reductions in the active army's force structure may deprive us of the units needed to build distribution systems, run rail nets, and pump fuel. Force reductions must leave units linked to bulk fuel transport in the active component if the army wants a quickly deployable force. It is essential that logisticians planning tomorrow's contingency operations be able to sustain their combat forces. Therefore, it is equally essential to identify the most efficient fuel transport system and the units needed to operate it.

---

[21] Ibid.
[22] Howard V. Nichols, "Operational Level Logistics: An Examination of the U.S. Army Logistics Doctrine for the Operational Level of War," MMAS Thesis, Command and General Staff College, Ft. Leavenworth, 1984, p. 2.
[23] Brinkley, p. 32.
[24] Richard P. Dacey and Gregory J. Rosenthal, "The Single Fuel Battlefield," *Army Logistician*, p. 2-4, January - February 1989.

Finally, the army cannot practice theater-level support operations in peacetime. Funding levels and political considerations preclude large scale exercises on foreign soil as demonstrated by the reduced REFORGER 1990 exercise. Today, theater-level sustainment is conceived in schools and command post exercises, and equipment is tested on a small scale, but the whole system will not be tested unless a major conflict breaks out--exactly when it must function without a hitch.

Doctrine, equipment, funding, and force structure provide compelling reasons for increased awareness of our fuel supply challenges. In light of these reasons, logisticians and operational planners alike should examine the challenges of fueling operational maneuver.

Theory

Examining these challenges begins with noting the sustainment imperatives set forth in army doctrine. These concepts provide the framework of the monograph's analysis by providing the criteria for evaluating transport methods. This section relates the criteria of the monograph analysis to classical military theory. These criteria are linked to theory via the sustainment imperatives.

Clausewitz writes that

> Theory will have fulfilled its main task when it is used to analyze the constituent elements of war, to distinguish precisely what at first sight seems fused, to explain in full the properties of the means employed and to show their probable effects. . . Theory then becomes a guide to anyone who wants to learn about war from books. . . It is meant to educate the mind of the future commander, or, more accurately, to guide him in his self-education, not to accompany him to the battlefield.[25]

Thus, it is appropriate to use theory to examine, even in an indirect manner the questions of fueling operational maneuver. Even though the internal combustion engine's application to war was unforeseen by classical theorists, their ideas still provide us with templates to critically examine today's operations undertaken using or supporting the automotive engine.

The U.S. Army's doctrine for combat operations lists five sustainment "imperatives" essential to the successful conduct of military operations. These are: anticipation, integration, continuity, responsiveness, and improvisation.[26] While the degree to which each is discussed in classical military theory varies, they all have links to this body of enduring thought. The first of these is anticipation.

Field Manual 100-5 defines anticipation as foreseeing future operations and their demands for sustainment with accuracy.[27] Our doctrine enjoins the planner to "visualize the entire course of a major operation or campaign while planning specifically for the phase that is under way."[28] In the discussion of the culminating point, Clausewitz explains that as an attacker moves away from his

[25]Clausewitz, p. 141.
[26]*FM 100-5*, p. 62.
[27]Ibid.
[28]Ibid.

sources of supply and is forced to invest fortresses, occupy territory, and provide security for his lines of communication, he experiences loss of combat power.[29] In this passage he is explaining the general outline of a campaign so that the reader can foresee the difficulties he confronts. In many other examples, Clausewitz gives descriptions of the battlefield and the campaign so that the reader can anticipate the friction associated with military operations before actually having to experience combat. Clearly, Clausewitz believes that anticipation was an important attribute of the commander or staff officer. Today anticipation is manifested in operational plans that are flexible, complete, and fully integrated with a feasible means of support.

Several theorists express the imperative to integrate maneuver with sustainment planning. The first of these, Sun Tzu, states that logistics calculations are a part of the art of war, explaining that among the elements of war are measurement of space, estimation of quantities, calculations, and comparisons.[30] Clausewitz urges his readers to conceive the army and its (logistical) base as a "single whole" because the army cannot fight without sustainment.[31] Perhaps the strongest statement of the case for integration is stated by Mikhail Tukhachevskiy: "The command group that has undertaken the operation and drawn up the operational plan but has not coordinated it with respect to logistics is criminal in its actions."[32] Anticipation of requirements and integration with operational plans help sustainment concepts meet the needs of the force and meet the imperative of continuity.

The theorists discuss the imperative of continuity of support to military undertakings. Clausewitz believes that convoys traversing lines of communication are relatively well protected and hence free to operate continuously. He states that a single convoy is a low-payoff target. Although it is vulnerable to attack, the enemy cannot haul away the cargo, thus making the attack of little value. Even if the enemy destroys the supplies, one convoy provides such a small portion of the army's total needs that it will hardly be missed. Therefore, the convoy is protected more by its "situation" than its escort's protective capability. "We may therefore conclude that ... attacking a convoy is strategically not very advantageous. It promises worthwhile results only in the unusual event of seriously exposed lines of communication."[33] Generally, brief supply interruptions don't bother Clausewitz except in the case of fodder--the nineteenth century's mobility fuel--sent to artillery and cavalry units forced to remain stationary for a long time. He notes that interruptions in fodder supply destroy these units and in static situations, they actually become liabilities.[34] Tukhachevskiy states bluntly that uninterrupted supply is essential, and that the planner is obliged to plan for the entire period of battle and successive operations so that no lapses in supply support result.[35]

---

[29]Clausewitz, p. 527.
[30]Sun Tzu, *The Art of War*, Oxford University Press, London, 1963, p. 88.
[31]Clausewitz, p. 341.
[32]Mikhail Tukhachevskiy, *New Problems in Warfare*, Reprint by Art of War Colloquium, U.S. Army War College, Carlisle Barracks, Pennsylvania, 1983, p. 49.
[33]Clausewitz,p. 555-556.
[34]Ibid. p. 347.
[35]Tukhachevskiy, p. 48.

Though not specifically mentioned in classical theory, responsiveness is a requirement of military operations described by both Sun Tzu and Clausewitz. Sun Tzu describes forms of battle where situations constantly change and states that the "skillful commander seeks victory from the situation," and "turns misfortune to advantage."[36] The sustainment structure of the army clearly must respond to changes on the battlefield allowing the army to pursue the enemy with vigor. He notes the importance of providing supplies and equipment to maneuvering troops by stating "it follows that an army which lacks heavy equipment, fodder, food and stores will be lost."[37] Clausewitz is more prescriptive on this topic, suggesting ways to maintain the responsiveness of the sustainment structure with lengthening lines of communication. Mitigating the effects of extended LOCs requires repairing and policing roads, capturing fortresses, and treating inhabitants well.[38] Such actions preserve the responsiveness of the supply system. The reward of maintaining responsiveness is the ability to concentrate superior combat power at the decisive point. This requires the commander to, among other things, sacrifice non-essentials for essentials.[39] Since even a responsive system may be eventually stretched beyond its limits, clever logisticians may have to improvise means to maintain combat power in such situations.

The classical theorists also have definite ideas about improvisation. When the logistical support structure of an army is less sophisticated, improvisation is often the rule rather than the exception. Sun Tzu observes that one of the enemy bushels (or carts, in some translations) is worth twenty of your own.[40] Outlining four ways to support a field army, Clausewitz explains that three of them are variations of scavenger logistics--living off the land and its civil population. Like Sun Tzu, he places value on captured enemy stores, noting that these were one of the main advantages of the attack. However, captured wealth cannot compensate for the diminishing combat power during an attack.[41]

Although the classical theorists fail to explicitly list the imperatives of AirLand Battle sustainment, they clearly embrace the concepts. These imperatives have enduring natures characterizing warfare since the earliest times, and the concepts become more important as armies demand more and more sophisticated logistical support. This paper uses one further criterion that the theorists advocate--minimizing overhead.

Any sustainment system must deliver support economically, with minimum amounts of fuel and manpower consumed in the delivery process. Simply put, this criterion may be called minimizing overhead. Sun Tzu clearly understands the problem with transporting supplies over long distances: " In transporting provisions for a distance of one thousand *li*, twenty bushels will be consumed in delivering one to the army... If difficult terrain must be crossed even more is

[36]Sun Tzu, pp. 93 and 102.
[37]Ibid. p. 104.
[38]Clausewitz, p. 347
[39]Ibid. p. 197
[40]Sun Tzu, p. 74.
[41]Clausewitz, p. 332, 566, and 569.

required."[42] Clausewitz stresses the need to compare only fighting forces when calculating one's correlation of forces. Those that are securing lines of communication or investing fortresses are committed elsewhere. He further notes that as the attack progresses, more and more troops are needed to secure the LOCs and exploit the resources of the captured territory. Eventually, the "tail" draws so many fighting resources from the army that it is no longer superior in combat power to the enemy and is precluded from further advance without risking defeat.[43]

In summary, the criteria for analyzing fuel transport means are rooted in theory. FM 100-5 lists five of the criteria as the AirLand Battle Sustainment Imperatives: anticipation, integration, continuity, responsiveness, and improvisation. Though not recognized by our doctrine, the sixth criterion, minimizing overhead is critical to evaluating any sustainment effort and is likewise recognized by military thinkers of the past.

The criteria suggested by the theorists and discussed above lead to a number of specific questions used to evaluate each method of transport. These questions should be the focus of operational planners as they design the bulk fuel transport system for the theater of operations. Briefly, these questions and their related criteria are:

<u>Anticipation</u>:
What is the method's ability to surge to meet future requirements?
What is the online storage capability to allow drawdowns in an emergency?

<u>Integration</u>:
What is the method's capability to provide fuel while it's infrastructure is under construction?
Are there long lead times or exceptional resources required to utilize the method?

<u>Continuity</u>:
How vulnerable to interruption is the supply provided by the method?
Can it deliver at reduced capacity after mechanical failures or sabotage?

<u>Responsiveness</u>:
Can it transport other classes of supply? If so, how much modification is required?
Can it be focused to other areas in the theater? If so what other resources are necessary?
Can it be built in time to support the campaign?

<u>Improvisation</u>:
Can the method be adapted to other supply or transport priorities or for other purposes?
It is likely that the method can be utilized with host nation assets?

---

[42]Sun Tzu, p. 75.
[43]Clausewitz, p. 527.

Minimize overhead:

What are the transportation and construction requirements for the necessary infrastructure?

What forces are necessary to operate and protect the infrastructure required by the method?

These criteria-based questions form the framework of the analysis. They are used to evaluate and compare the strengths, weaknesses, and vulnerabilities accruing to a force using either pipeline, rail, water, or highway transport. The answers to these questions, based on the hypothetical 21st Corps and its imaginary theater provide insights for planners and doctrine writers. First however, the fuel requirements for the corps must be determined.

Fuel Requirements for the Contingency Corps

Logisticians approach the problem of estimating fuel consumption for large units using two basic methods. FM 101-10-1, *Staff Officer's Field Manual: Organizational, Technical, and Logistical Data Planning Factors* uses both population and unit type as the basis for estimations.

Population based requirements, according to the manual, are for large units or entire theaters. It notes that these consumption rates may vary widely based upon a large number of factors. Among these are climate, force structure, mission, and combat intensity. The planning figure for bulk petroleum is 53.7 lb. per man per day.[44] Translated into gallons, this figure suggests that the 83,418-man contingency corps uses 640,575 gallons of fuel per day.[45] Since this figure forces the assumptions of "average" combat intensity and temperate climate, there are ways to factor such variables into the estimate. One way is through bulk planning factors given by unit in the FM 101-10-1.

The bulk planning factors method considers unit equipment, manpower, and climate to provide more detailed fuel consumption estimates. The estimate procedure uses fuel consumption factors representing hourly or mileage-based fuel consumption estimates for thirteen different categories of equipment held by a particular type unit. For example, factors representing track vehicle fuel consumption differ between tank battalions and mechanized infantry battalions mainly because of the consumption characteristics of their nearly equal number of tracked vehicles. Each fuel consumption factor is multiplied by corresponding numbers from a "usage profile" that reflects the climate or location where the unit operates. For example, usage profiles for the desert Middle East minimize the operating hours of amphibious equipment. Presently, the bulk planning factors section of FM 101-10-1 lists only the divisions and a few non-divisional aviation and artillery units of 21st Corps. Using the "standard profile" for consumption, these elements consume 1,159,683 gallons[46] of fuel each day. This is nearly twice the demand forecast for the entire corps based on the other

[44]*FM 101-10-1, Staff Officer's Field Manual Organizational Technical and Logistical Data Planning Factors*, Department of the Army, Washington, 1987, p. 2-5.

[45]For units and TOE strengths, see Appendix A. The gallon figure is the product of the planning consumption rate and the strength.

[46]The "POL intense" usage profile increases this figure to 1,178,033 gallons--an increase on only 1.6%.

estimating procedure. Clearly, there exists a wide discrepancy in the unit based and population based estimates requiring some type of compromise.

For the basis of this study, the methods are combined to provide an estimate of the 21st Corps' fuel consumption. First, some supply and transportation units are assumed to remain at the pc ɔf debarkation to forward supplies and provide a base of operations. All other units participate in a maneuver inland. Of the maneuvering units, most are listed in the bulk planning factors section of FM 101-10-1, as explained previously. Others have no such listing. The consumption for the units not listed is estimated using the population based method. While this probably provides an overestimate of actual fuel consumption, it provides a starting point to illustrate the planning considerations of fueling operational maneuver. Appendix A lists the 21st Corps units, indicates whether they deploy inland, and shows their estimated daily fuel consumption.

The figure of interest is the daily number of gallons projected for the maneuvering corps. Based on the estimate of Appendix A, this figure is 1,269,625 gallons. For convenience, this is rounded to 1,270,000 gallons. This figure represents the amount of bulk fuel which must be delivered to the forward elements of the COSCOM each day to maintain the tempo of combat operations. The sustainment planner must plan to deliver over one and a quarter million gallons of fuel each day just to satisfy consumption, not counting requirements to build up stocks for emergencies.

The planner has several doctrinal tools to assist his planning. Having established criteria for evaluating transportation means based on the FM 100-5 sustainment imperitives, and having established the sustainment requirement, we next investigate the doctrine concerning bulk fuel transport.

Operational Sustainment Doctrine

The U.S. Army recognizes six Operational Operating Systems. These are the major categories of activities that occur during a campaign, and for which the operational commander's staff must plan. These are: movement and maneuver, fires, protection, command and control, intelligence, and support.[47] As a subset of support, sustainment is concerned with all actions producing combat power. A further subset, Combat Service Support (CSS), involves the supply and transportation aspects of sustainment. The aim of CSS doctrine is explained by Field Manual 100-16, *Support Operations, Echelons Above Corps.* "Commanders must be conscious of their staying power and ensure that their combat forces have the resources to fight effectively from the onset of the battle to its successful completion."[48]

Commencing at the highest levels, sustainment doctrine delineates the responsibilities of agencies involved in providing bulk fuel. First, it designates the U.S. Army forces in theater as the

[47]TRADOC Pamphlet 11-9, (Draft), Fig. 4.7.
[48]*FM 100-16*, p. 1-9 to 1-10.

operating agents for inland distribution of petroleum, oils, and lubricants (POL) to all U.S. forces. In order to execute this responsibility, the army commander (usually the commander of the Theater Army) delegates the authority for accomplishing this mission to a number of subordinate commanders. In addition to the logistics planners of the operational commander, quartermaster groups, transportation agencies, as well as engineer headquarters are involved in the planning and operation of the bulk POL distribution systems.

Most heavily involved in bulk fuel planning is the Theater Army Petroleum Group. This is the major fuel distribution agency with a theater. A contingency corps, such as 21st Corps, contains only the "kernel" of this group--a Petroleum Supply Battalion. Whatever the level of the command, the petroleum operators are directly responsible for centralized distribution of bulk fuel in the theater, commanding pipelines within the zone, establishing liaison for host nation support, maintaining quality surveillance of products, and finally, organizing the command and system for growth as the theater matures.[49] This command also arranges with the theater transportation command for transport of bulk fuel outside of the pipeline system.[50]

The principal transportation operating agency within the theater is the transportation command. It is responsible for all motor, rail, air, and inland waterway operations within the theater, but does not command motor transport units specifically designed to haul bulk petroleum. Also impacting on the POL distribution systems is the TRANSCOM's responsibility for terminal operations (pipeline system terminals are excluded) and highway regulation. It also commands the forces involved in these transportation operations.[51] Significantly, the commander of the transportation command (or the transportation group commander in a contingency corps) is responsible for recommending transportation policies to the theater army commander.[52] Such policies could impact on distributing the total transportation load among modes as well as the maintenance of the transportation infrastructure.

Responsibility for the transportation infrastructure lies with the Theater Engineer. The Engineer Command (ENCOM) of the Theater Army or Engineer Brigade of the deployed corps repairs existing infrastructure or builds new facilities. As stated by FM 100-16, the engineers

> Plan, design, supervise, and perform, as required, the construction, maintenance, repair, or rehabilitation of airfields, ports, pipelines, roads, railroads, and inland waterways....Construct and repair...bulk petroleum storage and distribution systems...[53]

The engineers also coordinate host nation support for repairs to the transportation infrastructure.

---

[49] Ibid. p. 6-18.
[50] *FM 700-80, Logistics,* Department of the Army, Washington, 1982, p. 12-1.
[51] *FM 100-16,* p.6-18.
[52] *FM 10-67, Petroleum Supply in Theaters of Operations,* Department of the Army, Washington, 1983, p. 4-3.
[53] *FM100-16,* p. 9-2.

Thus, a large number of headquarters are involved in bringing fuel to the corps. Logistics planners at the operational command level provide estimates, concepts, and priorities before and during combat operations. POL groups and battalions transport fuel in pipelines and on highway trucks, in coordination with transportation commands and groups. Finally, the engineer command or brigade provides the infrastructure to accomplish the mission. These functions are linked to the major combat operations undertaken during the course of the campaign by doctrine.

In addition to establishing responsibilities for fuel transport, operational doctrine discusses the relationship between the combat operations and sustainment capabilities. This relationship results in campaigns that consist of phased operations and staged operational movements. In this context, phasing refers to the time dimension while staging refers to spatial dimensions.

The bulk fuel supply system for an immature theater must be developed in phases because of the extensive infrastructure involved. Generally, a wholesale system begins with hoselines extending from hastily moored tanker ships and airlifted fuel. Later, both collapsible and bolted steel tanks may be added. Eventually, coupled metal pipelines and hoselines link ports and corps storage facilities. The system is designed from the start to be flexible during its expansion, so that as demand increases, parallel pipelines and more storage may be added. The system also extends in length toward the combat zone and potential airfields.[54] The extension in support of combat operations naturally leads to the idea of staging.

Staging is the movement of sustaining bases toward the combat area and is essential to campaigns covering great distances. Staging cuts the length of tactical lines of communication allowing units to concentrate their resources on their battles rather than on hauling supplies. The operational commander balances the risk of extending his forces from his bases against placing bases close to the battle. He also balances the risks of meeting immediate supply and transportation needs versus deliberate preparations like stockpiling and building infrastructure for increasing future combat power.[55] As part of the sustainment system, the POL distribution system is likewise staged. Throughout all phases and stages however, it delivers fuel to bases as far forward as possible with the fewest possible changes in transport mode.[56]

Transport modes are discussed relatively little in operational sustainment doctrine. A few comments are worthy of note concerning the various methods of transporting bulk fuel. FM 100-16 states bluntly that the order of priority of modes is pipeline, inland waterway, rail, motor, and air.[57] Another manual adds that the pipeline is "generally" the most economical and effective means, but adds that it is susceptible to pilferage and enemy action. Under some conditions, other means may be more desirable.[58] Inland waterways are vulnerable to enemy sabotage and difficult to repair, in

[54] *FM 10-67*, p. 3-1.
[55] *FM 100-5*, p. 68.
[56] *FM 10-67*, p. 2-1.
[57] *FM 100-16*, p. 6-47.
[58] *FM 100-10*, p. 7-1.

addition to being somewhat scarce, notes FM 701-58.[59] While airlift is responsive and has no requirement for ground LOC security, it is always a shortage commodity. Therefore airlift should not be planned for routine resupply of "other than priority cargoes."[60] Thus sustainment doctrine clearly states its preference for pipelines and against airlift as the bulk fuel supply transport modes.

Now that the criteria, theory, and operational doctrine concerning bulk fuel distribution is clear, the analysis can commence. The analysis allows the reader to judge the relative strengths and weaknesses of each transport mode as applied to the 21st Corps. This creates a paradigm to assist future operational planners in selecting transport modes and priorities commensurate with their given situation.

Pipeline Transport

In terms of capacity, pipelines are the most efficient movers of large quantities of liquid products. As mentioned in the monograph introduction, U.S. forces used them extensively in the European Theater of Operations during World War II. Counting all theaters, the Army laid some 3,000 miles of pipeline during the war.[61] Since then, they have appeared in a number of conflicts including those in Vietnam[62] and the Falkland Islands.[63] Permanent, buried pipelines and extensive terminal facilities service U.S. forces in Korea and Western Europe.[64] This section applies the criteria-based questions outlined above to evaluate pipeline transport as a means to deliver bulk fuel to the 21st Corps. Since the characteristics of the pipeline itself are tied to its intended capacity, we must first examine the system itself.

Constructing a pipeline of the requisite size to supply a force 200 kilometers distant is a massive undertaking. The system designers must account for the 1,270,000 gallons per day capacity from the very start. The 21st Corps' pipeline should be constructed of 8" nominal diameter aluminum tube extending approximately 210 kilometers.[65] Though the fuel must travel a 200 kilometer straight line distance, the pipeline's length is greater to allow for grade changes and curves. This length requires twenty-seven five-mile sets of military standard pipe. Average terrain requires ten

---

[59] *FM 701-58, Planning Logistic Support for Military Operations*, Department of the Army, Washington, 1987, p. 8-20.
[60] Ibid.
[61] Robert W. Metz, "Military Pipeline Operations," *Engineer*, , p. 17-18, Summer, 1987.
[62] Joseph M. Heiser, Jr. *Vietnam Studies: Logistic Support*, Department of the Army, Washington, 1974, pp. 77-81.
[63] Kenneth L. Privratsky, "British Combat Service Support During the Falkland Islands War: Considerations for Providing Operational Sustainment to Remote Areas," Research Monograph, Command and General Staff College, Ft. Leavenworth, Kansas, 1986, p. 33.
[64] These systems are discussed in the following articles: Urson S. Bacle, "Trans-Korea Pipeline Modernization: An Update," *Army Logistician*, pp. 27-28, March-April 1988. Gary W. Bradley, "The Trans-Korea Pipeline: Will There Be Enough Fuel?" *Army Logistician*, pp. 2-6, November-December 1987. and A.J.T. Hofman, "The Central European Pipeline System: Another Form of Transport," *Defense Transportation Journal*, pp. 31-33, June 1983.
[65] *Technical Manual 5-343: Military Petroleum Pipeline Systems*, Department of the Army, Washington, 1969, pp.6-5 to 6-16, and pp. 3-51 to 3-54. Appendix B lists the requirements for the system taken from the Army Facilities Components System.

suspension bridges, and nine pumping stations.[66] The line requires at least three intermediate terminals to provide supply and storage space so that pumping operations may continue on parts of the line even if one leg of the line is disabled. Normally the terminal design allows for six hours of operation after a leg of the pipeline is shut down. The capacity of this line is 1355 barrels per hour,[67] which is 7% above the Corps' daily consumption.

Increasing capacity to meet projected requirements is a primary need for a method to satisfy the criterion of anticipation. The only way that the pipeline system can surge in anticipation of greater requirements is to increase line pressure. This increases the flow all along the pipe. During normal operations three pumps run at each of the nine pumping stations, with one pump at each station in reserve. This allows the crews to maintain or repair one pump while maintaining full flow in the line. In emergency situations, however, all four pumps can be engaged to increase the flow. On this pipeline, emergency capacity is 1,744,000 gallons[68] in 24 hours, or 27% above rated capacity. The need to repair and perform routine maintenance on pump engines dictates that emergency operation only be sustained for a limited time. The long term means to increase capacity of a pipeline system is to build a second, parallel line. While this is generally not as much work as building the first line along a given route, it is still a major undertaking. Beyond that, supplemental methods of transport must be used to increase capacity over the long term.

Another requirement based on the anticipation criterion is to provide drawdown capacity to meet emergency requirements. Given that intermediate terminals are complete, limited online storage is available for drawdowns during supply interruptions. However, this capacity is designed to achieve continuity, rather than supply a surge capacity. Fuel can be dispensed to users or to alternate transport means at the intermediate terminals. Thus, if excess bulk transport capacity (rail, water, or highway) can move to an intermediate terminal, additional fuel could be hauled forward. This capability is based on the availability of additional transport means, not on the pipeline characteristics itself.

The integration criterion dictates that the method of transport be able to function through all phases of the campaign, even while it's infrastructure is under construction. Meeting this criterion, the pipeline has excellent capability to deliver to intermediate points during its construction. The engineer units constructing a pipeline stage their operations and install temporary pipeheads at points along the line. These temporary pipeheads can supply products to retail distributors such as COSCOM Supply and Service Companies. Such units can also receive products at the three intermediate terminals. In fact, the doctrine indicates that temporary pipeheads may be moved every two to three days during the line's construction. After the infrastructure is complete, the criterion of continuity becomes the paramount issue.

---

[66] On level ground, stations should be 15 to 16 miles apart. Rolling terrain and increases in elevation necessitate closer spacing.

[67] At this rate, the line can pump 1,365,000 gallons in twenty-four hours.

[68] *TM 5-343*, p.6-5.

Pipelines satisfy the continuity criterion because they are difficult to destroy, are easy to repair, and are designed to overcome brief line breaks. Additionally, they can operate through all weather and climate conditions while maintaining full capacity. During normal operations, they operate 20 or more hours per day. By nature and design, they are a dependable and safe method of fuel transport.

Generally, pipeline flow is difficult for the enemy to disrupt. They are laid along concealed routes where ever possible, but even in the open they present difficult targets for aircraft lacking precision munitions. The major threats comes from sabotage by enemy special operation forces and theft by civilians in the area. While it's difficult to break the line in two, leaks are generally easy to open. During the Vietnam War, pipeline losses sometimes reached 2.5 million gallons per month in the Qui Nhon area. This prompted the commanding general of the 1st Logistics Command to conclude: "... if assets are not available to protect and secure the pipeline (although it can easily be repaired), it is more efficient to resupply fuel by truck, rail, or barge." Nevertheless, the Army continued operating its line from Qui Nhon to Pleiku.[69] Pilferage and sabotage may be reduced by aggressive patrolling, but a determined enemy or desperate thief can eventually break the line.

Surface-laid pipelines are generally easily repaired. In most cases a sleeve-like saddle clamp is tightened over the leak, or adjoining pipes are realigned to reseal their common joint. Such repairs take only a few minutes. A completely separated line, particularly one that has been demolished using explosives requires new pipe sections, cutting, and joining using standard clamps. Still, this is not a major problem. Fire constitutes the major hazard to workers and the chief impediment to repairs. Luckily, today's JP-8 fuel is less likely to ignite at a leak site than the MT-80 gasoline used in World War II.

During repairs, continuity is provided by the design of the system. Three intermediate terminals divide the 210 kilometer pipeline into four legs. Should one leg of the line be disrupted, the unaffected legs continue to pump into or out of the adjacent intermediate terminals. On the 21st Corps pipeline, each terminal needs a capacity of 700,000 gallons, based on twice the line's capacity over a six hour period. During normal operation, half of the tanks at a given terminal would remain empty and the other half full to allow the terminal to either receive or discharge fuel in anticipation of either its downpipe leg or uppipe leg being interrupted. Thus, the unaffected legs of the line can continue to operate for six hours after an interruption. Generally this allows enough time for repair crews to restore service. More collapsible tanks may be added to the intermediate terminals if the logistician believes that more time is needed for repairs. Still, extensive sabotage or mechanical failures could conceivably shut down the line.

A pipeline has only limited ability to run at reduced capacity if a pumping station is put out of action. While the design of the pumping station provides the redundancy of an extra pump, the loss

---

[69]Heiser, p. 77.

of two or three pumps at a single pumping station severely reduces the product flow. The loss of an entire pumping station stops the flow until the station is repaired.[70]

In terms of the continuity criterion, pipelines have several strong points. They are generally difficult for an enemy to break unless he places soldiers on the ground to attack it. Even so, extensive damage is easily and quickly repaired. Finally, the flow of product is unlikely to be interrupted due to the intermediate storage designed into the system. Judged on continuity, pipelines appear to be advantageous methods for transporting fuel.

The responsiveness of the pipeline system to changing needs of the operational commander centers on three abilities. These are: the ability to convert to other products, the ability to divert flow between geographic areas, and the ability of the troops to construct the system in time to support the campaign. We consider first the ability to respond to various product needs.

Pipelines switch between different petroleum products as a routine matter. The single fuel battlefield makes such capability less important. Although situations could dictate that specialized aviation fuels be pumped into the combat zone, for example. In such cases, no downtime is necessary. Usually different products are pumped behind one another without a physical buffer. Some mixing occurs at the interface of the products, but this interface product is "cut" to form a useable product or discarded. Alternatively, a "pig" can be inserted between products, although this takes more time and effort, requiring that the line be shut down while the pig bypasses pumps. Thus, one distribution system provides multiple products to respond to a commander's changing needs.

Though responsive in terms of product, it is impractical to move an installed pipeline to focus sustainment laterally. Moving an in-place pipeline involves even more work than building one in the first place because of the labor involved in dismantling the system. Tearing down the old system requires draining the line and results in double handling of the easily damaged pipe sections. On the other hand, branch lines may be laid from the main line to reach distant users, but this requires additional pipe and construction effort. The construction of the line may be diverted to follow the main operational effort, as was done in Normandy when General Bradley decided to send the bulk of 12th Army Group to the east instead of investing the Brittany peninsula.[71] Therefore, only during the construction phase do pipelines offer the commander the flexibility to redirect his sustainment without additional resources.

The major drawback to pipeline transport is the time needed to build the system. Current estimates indicate that from 2 to 10 miles of line per day may be constructed depending upon the terrain and efficiency of the work crews.[72] Planners during World War II estimated that pipelines would advance up to 20 miles per day, but were disappointed by advances closer to 5 miles per

---

[70] *TM 5-343*, Chapter 6 details the hydraulic design of the line.
[71] Ruppenthal, p. 510.
[72] *TM 5-343*, p. 2-2.

day.[73] At these rates, the 21st Corps pipeline takes anywhere from 13 to 61 days to construct with the most likely time being around 27 days.

Pipeline transport appears mediocre in terms of responsiveness. Positive factors are its ability to carry various petroleum products and follow the main effort of the campaign. On the other hand, it can take prohibitively long to construct and once in place, it cannot be refocused without a major effort. This lack of responsiveness is related to another weakness in terms of improvisation.

Pipelines do not provide the logistician with infrastructure or tools that can be diverted to other supply priorities, nor could a pipeline be speedily improvised from materials found in the theater. Pipelines are single purpose systems with no ability to transport products other than petroleum. Many petroleum pipelines could not even supply water because of their hydraulic design.[74] Pipelines require large amounts of pipe, tank storage, and specialized high volume pumps. There is little likelihood of finding such items in a theater to enable the logisticians to improvise a system. Thus pipelines do not lend themselves to improvisation in part due to the overhead of building them.

The overhead associated with a pipeline system comes from a number of activities. First the transport and construction of the pipeline comprise significant obstacles. Next, the system must be filled, consuming a surprising amount of petroleum product. Finally, operating and maintaining the system requires troop effort.

The transport and construction overheads associated with pipelines are their chief disadvantage. The components needed to build the 21st Corps pipeline are listed at Appendix B. The total shipping weight of these items is over 12,600 measurement tons.[75] This requires a strategic lift effort of 15 seagoing barges or one entire SL-7 ship. Within the theater, the pipe and equipment place additional burdens on port and storage facilities. Construction transport requires four tractor-trailer loads for each mile of pipe, with additional loads for intermediate terminals and pumping stations.[76] Construction of the line requires the Engineer Battalion Combat (Heavy) and augmentation from the Pipeline Construction Support Company. While the Combat (Heavy) Battalion is already part of the 21st Engineer Brigade, the company, of which there is only one in the active army, must be added to the troop list. In sum, moving the materials and constructing the system are massive efforts. Likewise initially filling the system may strain the fuel supplies.

Filling and testing the line requires a significant amount of fuel. Filling the line requires 16,086 gallons per mile. Additionally, intermediate terminals require 1,050,000 gallons to provide continuity in case of breaks. Thus the total overhead for filling the distribution system is 3.2 million

---

[73] Ruppenthal, p. 319 and p. 510.

[74] The hydraulic design is determined by the heaviest product to be transported. Water is heavier than petroleum products.

[75] *TM 5-343*, p. 3-51 to 3-54 provides the basic data for this calculation.

[76] David Gorczynski and David Auman, "Engineer Troops on a Pipeline Exercise," *Military Engineer*, p. 75, January-February 1988.

gallons amounting to two and one-half days of supply for the force. Fortunately, this is pumped through the system and requires no alternate transport, but its sheer amount may impede operations. During one phase of the breakout in Normandy, quartermaster units were unable to fill a newly completed length of pipeline because distributions to truck transports at the old supply point took all the available fuel. The upstream sections of pipeline could not supply enough for both consumption and filling the new line at the same time. Therefore the newly completed section was useless until the tactical situation allowed them to fill the line.[77]

The units required to operate and protect the line are another source of overhead. One Petroleum Pipeline and Terminal Operating Company (TOE 10-207) operates 100 kilometers of line and four pump stations.[78] It can also operate small bulk storage and issue facilities. Because the 21st Corps' system has nine pumping stations and over 200 kilometers of line, three such companies must be added to the Corps. Additional troop requirements are a Military Police Physical Security Company (TOE 19-97) to patrol the line, and three firefighting teams (TOE 5-510, one per terminal). Finally, a POL Operating Battalion Headquarters and Headquarters Company (TOE 10-206) is needed to control these units. These units represent a total strength of 793 personnel.

Thus the overhead associated with transporting, constructing, filling and operating a pipeline system is significant. Transporting and constructing require resources that could be devoted to bringing combat units into theater and moving them into the combat zone. Filling the system requires over two days of fuel, and merely operating the infrastructure requires almost enough soldiers to man an infantry battalion.

Pipeline transport favorably meets most of the six criteria established as evaluation standards. It fulfills the anticipation criterion with its ability to surge to 27% beyond rated capacity for short periods of time. It meets the integration and continuity criteria through its ability to provide large amounts of bulk fuel while the line is under construction and during pipe repairs. Pipelines are responsive to changing POL needs, but cannot be easily focused to new areas once they are constructed. Another negative point is that they do not lend themselves to improvisation--either through being easily constructed with indigenous materials or support of transport requirements other than POL. Finally, significant overhead displaces other priority shipping and construction requirements within the theater. Once built however, they provide economical and efficient transport of fuel.

Railway Transport

Logisticians have considered railroads to be mainstays of operational maneuver and sustainment for over 120 years. A product of the early nineteenth century, railroads were a major means of sustaining the Union Army during the American Civil War. Just a few years later, railroads assisted the deployment of Prussia's armies against the Austrians. While largely remembered for its

[77] Ruppenthal, p. 573.
[78] *FM 10-207*, pp. 2-1 to 2-3.

achievements of highway transport, the U.S. Army of World War II relied heavily on rail in the European Theater.

Today, nearly every nation has rail networks and rolling stock. In many areas of the third world it remains the primary long distance transportation means. In many cases the highway system of these nations is underdeveloped by comparison. Therefore, logisticians constrain themselves if they do not consider rail as a means to transport high tonnage items like bulk fuel.

Meeting the fuel needs of the 21st Corps is a minor challenge for a well-developed rail network. Assuming that the system has tank cars of 10,000 gallon capacity,[79] the 21st Corps would need 127 such carloads per day. Rail planning figures suggest 20 car trains over average terrain, and indicate that 10 trains can operate on a single track line each day. These figures yield a daily railway capacity of 200 cars, showing that even a single track line has capacity excess to the fuel transport mission. A true rail network operating within the theater would have much greater excess capacity available for other cargoes if sufficient rolling stock is available.[80]

The fuel transport mission presents only modest requirements for locomotives and tank cars. We assume line leading to the Corps Support Area is around 135 miles long, and could reasonably support traffic operating at an average speed of 12 miles per hour.[81] Under these circumstances, a locomotive and its crews could make one round trip per day. These operations would require around 130 to 140 tank cars, at least seven line haul locomotives, and a switch engine at each railyard. The analysis assumes that a single line system operates with the requisite 130 tank cars and limited other car types to allow flexibility in filling partial fuel trains to their 20 car capacity. Now that we have established the requirements for the transport system, we begin the analysis by considering this system's ability to operate beyond it's intended capacity.

Surging the fuel supply in anticipation of major operations may be accomplished in a number of ways using rail transport. Most obviously, some of the excess capacity of the line may shift from dry cargo or passengers to fuel if more tank cars can be found. Operators may find it possible to increase the speed of the trains, thereby running more trains each day. If more than one route to the corps is available, trains could travel in a one way loop, thus increasing the line capacity. Similarly, multiple routes could double or triple the cargo capacity of the system. Finally, if neither additional routes nor additional tanks cars are available, the expedient of "piggybacking" highway tankers on flatcars could increase fuel transport capacity of some trains. Thus, the railway affords the logistician flexibility to temporarily increase his system's capacity, depending upon the availability of rolling stock and parallel rail lines.

---

[79] *FM 55-20, Army Rail Transport Operations and Units,* Department of the Army, Washington, 1988, p. 8-5.

[80] Ibid. p. 1-15.

[81] *FM 55-15, Transportation Reference Data,* Department of the Army, Washington, 1986, p. 4-13 to 4-14.

Online fuel storage is only available at the expense of such precious rolling stock, however. If the railway operates with just enough tank cars to keep the corps supplied, they must be unloaded immediately into the Corps' ground storage tanks to free the cars for their return trip. Fuel handlers in the retail supply units often hesitate to download their deliveries because they anticipate moving. At one point in the European Campaign of 1944, one rail yard in France had over 2,000 rail cars awaiting unloading.[82] Since the 130 tank cars hold only 1,300,000 gallons, holding them for storage would provide little benefit for the 21st COSCOM and it would cripple the resupply operation. Thus, there is no capacity for drawing down fuel stocks in the transport system itself as a means of emergency supply. Any such storage comes at the expense of the transport system's capacity.

Large capacity and extensive infrastructure are the rail characteristics impacting on the criterion of integration. Large capacity is a major advantage of rail, but this capacity may only be delivered if the rail lines reach the desired destination.

A chief advantage of railroads is their high transport capacity even while some lines are undergoing rehabilitation. This allows railroads to satisfy the imperative on integration if a line can be opened early in the campaign. Triandifillov points out that hauling construction material for railway repair diminishes capacity while such repairs are underway.[83] The excess capacity of the railway serving 21st Corps means it can haul 1400 or more tons of cargo other than fuel each day. Only in the unlikely event that daily construction needs exceed 1400 tons would Triandifillov's prediction interfere with the fuel transport mission. Of course, the obvious fact that the cargo can only travel as far as the train itself brings up the problem of railway repairs keeping up with the advance of operational maneuver.

Rehabilitation of railways generally cannot keep pace with the advance of operational formations. Even the rehabilitation of only one line is sometimes beyond the capabilities of repair crews. This was the case in the European Theater in 1944. Logistics planners wanted to open at least one rail line per field army to support the advance. The plan called for supplemental lines to be opened later. During the breakout, however, railway repairs fell far behind the advance.[84]

The rehabilitation of rolling stock may similarly require long lead times, thus hampering the integration of rail transport in operational plans. Specialized skills and tools are required to repair railway cars and locomotives. With no railway units on active duty, the deployed U.S. forces initially depend upon host nation or civilian contractors to repair rolling stock. Even with proper tools and skilled labor, some rail equipment may be in such poor condition that bringing sufficient quantities up to operating condition requires a long time. A similar challenge faced U.S. troops in North Africa in 1943. The rolling stock of the local railroads was so small that it was inadequate for

---

[82] Bradley F. Smith, "The Role of Army Railroading at the Operational Level of War," Research Monograph, Command and General Staff College, Ft. Leavenworth, Kansas, 1989, p. 28.

[83] V.K. Triandifillov, Nature of the Operations of Modern Armies, SAMS Reprint, Ft. Leavenworth, Kansas, p. 177.

[84] Ruppenthal, pp. 544-545.

military purposes and equipment had to be shipped into the theater from the United States.[85] Thus initial combat operations proceeded without the benefit of full railway support.

Railroads can seldom be integrated with initial operational advances in a theater. The long lead times associated with railway and rolling stock repairs means that only under the most favorable conditions of enemy denial activities would any rail support be available. With the effective length of the line constrained by enemy inflicted damage, the corps is forced to rely on supplemental transport for its fuel forward of the point where the active line stops. Thus both long lead times and exceptional resources--including supplemental transportation means--will be required to integrate rail transport with the campaign plan. Only after the system is repaired and running does its capacity make it attractive to the planner, who must then concern himself with its continuity.

The imperative of continuity demands that the railway be relatively unaffected by enemy action. Yet, the railway's vulnerability to sabotage is a major disadvantage of this transport means. Generally, key bridges or tunnels are high payoff targets for saboteurs. These structures require relatively small efforts to destroy, but tremendous efforts to repair. During repairs, the line is completely out of action--no traffic may pass, thereby cutting the line capacity to nothing. Colonel T.E. Lawrence demonstrated the vulnerability of railways to irregular forces in his operations with the Arabs in 1917. He showed that the loss of a key structure of the line could cripple resupply efforts for days. The same is true today. Thus, saboteurs and unconventional operations can easily interrupt rail operations. Weather conditions, on the other hand affect operations little.

Railways are high capacity, all weather transportation means with generally good redundancy. Trains are unaffected by weather conditions, except when the infrastructure is damaged or blocked.[86] Examples of problems associated with weather conditions are floods, landslides, or deep snows. Night does not affect train operations, since they are able to move with equal speed in darkness. Trains are capable of operating around the clock with multiple crews. Mechanical failures usually do not affect operations, since multiple locomotives are generally available within a system and train size may be varied with smaller, less capable locomotives. Thus all weather operation and good redundancy help the railways meet the continuity imperative.

Redundancy is the key to continuity in rail operations. As mentioned, multiple locomotives are the keys to moving trains over the available lines in the event of mechanical failures. Similarly, redundancy in the rail net itself allows the rail operators to maintain continuous operations in the face of interdiction by saboteurs. Since the loss of a key structure in a single line system can stop the railway cold, it becomes important for the planner to devise means of opening multiple lines and securing more rolling stock than he actually needs for the mission. Each locomotive, tank car, or railway bridge becomes a high payoff target in rail systems operating with a paucity of equipment.

---

[85]Joseph Bykofsky and Harold Larson, *The Transportation Corps: Operations Overseas*, Center of Military History, Washington, 1957, p. 168.
[86]Smith, p. 18.

Increasing the numbers of lines and rolling stock not only increases capacity and fulfills continuity requirements, but makes the system more responsive to the operational commander's needs.

A complete rail system is one of the most responsive transport means available to the operational commander. It transports multiple classes of supply and passengers. A network of lines allows supplies to be focused to any point in the theater serviced by the rail net. On the other hand, the length of time to bring an existing but damaged system up to this standard constitutes a major resource drain. These points demand more complete development.

Transporting multiple products is a key question when considering the responsiveness of railway transport. This flexibility is one of rail's strongest points. Given appropriate rolling stock, railways can transport any conceivable commodity. In addition to the corps' fuel, a single locomotive can haul coal, dry cargo, refrigerated food products, or major end items such as combat vehicles. The railway can also meet the commander's need to quickly redeploy major units in a short amount of time. Thus many commodities are hauled using regularly scheduled train traffic. Even if special needs arise, changes to the train schedule are generally not difficult if multiple routes are involved. The flexibility of rail transport was indicated by the fact that after November 1944, more than half of all supplies hauled in the ETO by the U.S. forces went by rail.[87] Today as in 1944, rail traffic can direct its high capacity nearly anywhere the tactical situation allows.

The time required to rehabilitate the rail infrastructure is the chief impediment to its responsiveness. Army doctrine recognizes the magnitude of constructing rail lines and advocates using only host nation facilities. Constructing a single track line to support the 21st Corps would take over six months of effort by the entire 21st Engineer Brigade. Merely rehabilitating the lines based on "average" damage by the enemy could take up to two months.[88] Reconstructing rail lines can consume much in the way of resources--both troops and time.

Historical data quoted by Triandifillov indicates the difficulty of reconstructing railways. He based his observations on both French and Russian experiences during World War I. Depending upon the damage sustained, the French were able to rehabilitate 1 to 6 kilometers of line, while the Red Army spanned 7 to 10 kilometers each day. In his analysis, Triandifillov predicted that future warfare would see average reconstruction rates of 5 to 6 kilometers per day.[89] His prediction was conservative in at least one instance.

A vivid example of the resources required to rehabilitate rail lines comes from the U.S. campaign in Normandy. Shortly after Third U.S. Army turned east following the breakout from St. Lo, it outran its highway supply vehicles. A rail line was needed to haul fuel and ammunition to the leading elements at Le Mans. On August 12, 1944 Colonel Emerson Itschner, commander of the engineer troops in the Advance Section, Communications Zone, received the mission to repair the rail

---

[87] Bykofsky and Larson, p. 342.
[88] *FM 101-10-1*, p. 1-47.
[89] Triandifillov, pp.171-173, 176.

lines between Folligny and Le Mans. Deadline for the opening of the 135 mile stretch of track was 15 August--just three days later. During that time, his engineers rebuilt three bridges and many stretches of track, along with coal and water stations. The final bridge was completed just four hours before the deadline and thirty trains immediately went forward carrying fuel and ammunition. While this operation was an impressive feat, it required equally impressive resources. Over 10,000 men from eleven different engineer regiments worked continuously for most of the three days.[90] Another way to look at the tremendous resources required to rehabilitate railways is the fact that by the end of August, 1944, the ETO employed some 18,000 men in rail reconstruction.[91]

To summarize the responsiveness of railway transport, one must conclude that it is a two edged sword. On one hand, a complete rail system is wonderfully responsive to the commander, satisfying his needs for flexible, reliable, high capacity transport of all commodities. On the other hand, putting the system into adequate condition may require such massive efforts as to make reconstruction prohibitive for a short campaign.

Once in operation, railways' adaptability allows the logistician to improvise. As discussed with respect to the responsiveness criterion, rail transport is very flexible with regard to the commodities it can carry. Flatcars can even carry loaded POL semitrailers, thus facilitating onward movements. If sufficient tank cars are unavailable, fuel storage bladders or collapsible drums ("blivets") may be carried in open top gondola cars or boxcars. Rail equipment allows a wide range of improvisations to increase its capacity.

The rail infrastructure itself is amenable to repairs using improvised means. Tactical bridging was sometimes used during World War II to create both spans and piers for bridges. In one instance a captured railway gun provided U.S. Army engineers with the materials to improvise a bridge span. The huge gun carriage was lengthened and placed across a 104 foot gap just north of Marseille. This improvisation enabled traffic to cross weeks earlier than if the engineers had waited for the structural steel inbound from the United States.[92]

Thus rail equipment lends itself to improvisation from two standpoints. From the standpoint of flexibility, many different means may be used to haul the liquid cargoes to 21st Corps. From another standpoint, many parts of the railway infrastructure may be repaired using locally procured material. Such improvised repairs naturally lead to a discussion of the overhead associated with running the rail system.

Railroad systems consume several categories of resources. The operational planner needs to consider reconstruction materials and their transport, forces to operate and protect the system, as well

---

[90]Alfred M. Beck et al., *The Corps of Engineers: The War Against Germany*, Center of Military History, Washington, 1985, pp. 400-401.
[91]Ruppenthal, p. 551.
[92]Beck, p. 451.

as the fuel to run the trains. Upon analysis we find that the first category represents formidable amounts of material.

The construction and material transport requirements to rehabilitate a rail line are the biggest obstacles to utilizing this excellent transport means. Doctrinal planning figures state that for every 100 kilometers of track, logisticians should plan to use 15,384 tons of material and 382,400 man-hours of labor.[93] To illustrate the magnitude of this requirement, the material to rehabilitate a 200 kilometer stretch of line serving the 21st Corps will fill nearly 80 trains. Even if aggregate and crosstie materials are available locally, 1780 tons of steel rail still need to be shipped. The entire 21st Engineer Brigade needs to work over two months in its construction assuming that the necessary materials are on hand.

Initial construction of a rail line demands even more time and material. If the 21st Corps had to build its line from scratch, nearly $^1/_2$ million tons of materials and six months would be required. Even at this time, the engineers would be working seven days a week for 12 hours per day on nothing but the rail line. Thus the prospect of constructing new rail lines over extended distances during contingency operations is infeasible. Some new construction might be worthwhile, however.

A tank car loading station and connecting track to the source of fuel should be built. A standard 10 tank car loading facility is available thorough the Army Facilities Components System. The loading station requires about two weeks to build using one engineer battalion. Some 850 tons of material, consisting mostly of pipe and rails are needed.[94] Such a facility is needed for quick filling of tank cars at the port and to eliminate double handling of fuel from storage tanks to the rail cars.

To summarize, the overhead associated with building or reconditioning a rail system is overwhelming. Construction of new main lines is clearly beyond the capability of the corps. Repairing slightly damaged facilities could reasonably be undertaken, however. Limited construction of important facilities such as the rail car loading facility at the terminal is also worthwhile.

In the absence of a rail system operated entirely by the host nation rail, forces to operate and protect the rail system are modest. The core of a railway group is its Transportation Railway Battalion (TOE 55-225G) with 726 personnel. Detachments from a Diesel Locomotive Repair Company (TOE 55-247G) and Transportation Railway Car Repair Company (TOE 55-248G) are also needed if host nation support for these vital functions was unavailable. Protection of the line and rail yards would require a Military Police Physical Security Company (TOE 19-97).[95] Although not required initially, a railway group headquarters would be needed as more railway battalions move into

---

[93] *FM 101-10-1*, p. 1-47. Subsequent calculations in this and the next paragraph are based on figures from this reference.

[94] *TM 5-301, Army Facilities Components System--Planning,* Department of the Army, Washington, 1979 p. 70.

[95] *FM 101-10-2, Extracts of Non-Divisional TOE*, Department of the Army, Washington, 1977, pp. 14-3, 27-20 to 27-24, A-27, A-58 to A-59.

the theater to operate the expanding rail net. Thus, around 1216 personnel are needed to operate the rail system--a force roughly equivalent to one and a half mechanized infantry battalions. Unfortunately, there are no railway units currently on active duty within the U.S. Army.[96] Thus, our army might be unable to muster even these modest personnel demands.

The question of fueling the trains should be considered in examining the overhead, and its impact is surprisingly small. Locomotives consume around 2.5 gallons of diesel fuel per mile.[97] Even allowing two locomotives per train, and ten trains passing in one day, the fuel estimate for the operation over the 21st Corps' line is 15,000 to 17,000 gallons. This figure is roughly equivalent to half an M-1 Tank Battalion's daily consumption.

To summarize the observations on the overhead connected with hauling the 21st Corps' fuel by rail, we see two major obstacles. The first is the major efforts which may be needed to place the line into operation following enemy denial operations. The expenditure of engineer effort and time could well preclude effective use of the rail line during the campaign. Even if the host nation undertook the repairs and thus freed U.S. troops for other missions, the time and distance gaps from railhead to fighting forces could prove untenable. The second major obstacle is the fact that U.S. Army railroading is a disappearing art. There are few personnel to operate the trains and rail system. Again, host nation support will prove to be the key to our use of rail transport because the U.S. Army lacks the railway units to move into a theater on short notice.

Overall, rail transport is very attractive to the operational planner if the system can be put into operation. Its capacity allows significant surges, allowing the logistician to anticipate major combat operations. It meets the criteria of integration and continuity by virtue of capacity and redundancy of both rolling stock and lines. It provides flexible, all weather service for all classes of supply, thus meeting the responsiveness criterion. It is amenable to improvisation, both in its rehabilitation and in the means that may be employed to haul fuel using various expedients. The capacity and redundancy of an operating rail system is difficult to better with any other transport mode.

The other side of this matter is the resources necessary to reconstruct and operate the system. With no railway units in the active army, the U.S. is forced to rely on host nation support for train operation, at least initially. Since reconstruction of rail lines and yards is so labor and material intensive, contingency operations will likewise be forced into relying on foreign governments and contractors for the rail infrastructure itself. With such heavy reliance on host nation support, it's questionable whether short term contingency operations will be able to utilize railway transport at all.

Inland Waterway Transport

Armies have used water transportation throughout history. In the absence of transportation infrastructures on land such as highways or railroads, it provides the only feasible method of moving

[96] Smith, p. 3.

[97] *FM 55-20, Army Rail Transport Operations,* Department of the Army, Washington, 1988, p. 10-'1.

large numbers of men and their associated materiel. The U.S. Army's Transportation Corps offers this insight on water transport within theaters of operation:

> Compared to other modes of transport, an inland water system offers unequalled efficiency and productivity. It is also more efficient for moving liquid, bulk, or heavy outsized cargo into a theater where there is an abundance of connecting navigable rivers and canals and a limited number of roads and railways. This environment is almost always found in jungle areas and areas which have an extended rainy season.[98]

Many areas have extensive river systems with sizeable inventories of floating equipment. Since contingency operations may occur in such areas, it's useful to examine the potential of using water transport to move the 21st Corps' fuel.

Water transport is nothing new for the U.S. Army. Barge traffic forwarded 50% of the military supplies discharged at the port of Antwerp in 1944 and 1945.[99] Barges and landing craft carried equipment, ammunition, and fuel during the Vietnam conflict as well.[100] Logisticians faced challenges in planning utilization of watercraft because of the large variations of craft available in theater and the unpredictable nature of enemy denial efforts. Today, this situation is the same, although it is alleviated somewhat by standardized army-owned watercraft and by host nation agreements.

The watercraft available to the U.S. Army for bulk liquid movements fall into two categories. The first is the government-owned POL barge. This unpowered barge, 120 feet in length, carries 174,720 gallons of bulk fuel. It has a crew of four, and usually is towed by a 45 foot harbor tug, having a crew of eleven.[101] The other alternative for bulk transport is host nation vessels. While these vary widely, one example is a type of German river barge that was used during a recent REFORGER exercise. This craft carried 132,000 gallons and demonstrated that it could be offloaded at undeveloped sites during the training exercise.[102] The capacities and number of the watercraft themselves usually determine the capacity of an inland waterway system.[103] Given this fact, we can determine the approximate numbers of government-owned barges needed to supply the 21st Corps' fuel needs.

Even though each barge carries over ten percent of the corps' daily needs, the logistician needs more than thirty barges to supply the corps. Since the formation is 200 kilometers from its sustaining base at the port, a river or canal could easily span 20% more distance, or 240 kilometers to cover the distance to the corps' POL terminal. Given the planning figures for barge traffic of 6.4 kilometers per hour and 20 hour day, this means that each 37 $^{1}/_{2}$ hour trip would require two days'

---

[98] *FM 55-50, Army Water Transport Operations,* Department of the Army, Washington, 1985, p. 4-1
[99] Beck, p. 364.
[100] Heiser, p. 168.
[101] *FM 55-15,* p. 5-9; TOE 55-530.
[102] Robert McHenry, "Petroleum Support for REFORGER," *Army Logistician,* p. 12-14, Nov-Dec 1988.
[103] *FM 55-15,* p. 5-22.

travel. The corps' fuel demand dictates that at least eight barges deliver fuel each day. This means that sixteen barges must be traveling toward the corps terminal on any given day. Sixteen must also return. This system requires at least 32 barges--more if the planner wants any redundancy to meet emergencies. Sixteen or more tugs are needed to tow these barges, with the exact number depending upon the current and channel characteristics. Thus even the minimum number of watercraft required to fuel the 21st Corps represents a sizeable fleet. Now that the transportation system components have been identified, we begin the analysis by considering the system's ability to transport emergency loads.

Using this fleet to surge its capacity in anticipation of major operations may be accomplished in a number of ways. First, if the waterway and number of barges allows, each tug might tow more barges with some sacrifice in speed and maneuverability. The operating hours or speed of the tug could be increased to a certain extent. Calculating exact surge capacities is difficult and, as historians point out, barges are slow means of transport.[104] Drawing upon "online" storage with barges presents the same problem as with railway tank cars--using bottoms for storage takes them away from their primary mission of hauling fuel forward. Therefore, barges present only limited surge capability to the operational commander.

The ability of the operational planners to integrate waterway support into their campaign plan is likewise limited. If the waterway infrastructure has been destroyed by a determined enemy's denial operations, many weeks of repairs may be necessary to restore it to operating condition. In the meantime, the logistician must devise alternative methods of fueling his formation. The difficulties associated with repairing damaged waterways shows their vulnerability.

The continuity of waterway operations is subject to interruption from a number of hazards. These include sabotage, enemy mines, and weather. All can potentially stop inland navigation for long periods of time.

The vulnerability of waterways to sabotage is a major disadvantage. The loss of a lock, destruction of a bridge over the waterway, or sinking of a barge in a channel could cripple resupply efforts for days. Locks are easy to destroy, but particularly difficult to repair. Waterways are also vulnerable to enemy mining operations.

The Allies exploited this vulnerability by mining Danube River in April 1944. Most of Germany's oil was hauled from Rumania by barges and at that time the Danube carried twice as much freight as the parallel rail lines. The Allied mining crippled the oil transport operation and almost completely halted barge traffic by May. By mid June, 39 vessels had been sunk and many others damaged, shutting off the flow of precious oil to Germany.[105] The Allies thus denied the Third Reich an efficient and high capacity means of transport. Similar enemy activities could

[104]Bykofsky and Larson, p. 356.
[105] Robert Goralski and Russell W. Freeburg, *Oil in War*, William Morrow and Company, New York, 1987, pp. 268-270.

cripple the 21st Corps, since losing even one barge represents a significant portion of the transport systems' capacity.

Weather also affects the continuity of operations on inland waterways when it causes floods, freezes, or long term drought.[106] The Albert Canal in Belgium froze during the winter of 1944-45, forcing the army to employ hastily improvised icebreakers. Later, floods halted all inland waterway operations in ETO for nearly a month in January-February 1945.[107] Even though weather sometimes disrupted operations, the waterways still made significant contributions to the transportation effort in the European Theater.

Continuity is also maintained by having extra towing vessels. Since nearly any tug can tow the barges, a mechanical failure of one component does not necessarily stop the waterway system. Therefore it's imperative to have spare vessels and repair parts available as well as to have data on potentially available host nation vessels within a theater of operations.

To summarize the aspect of continuity in operations, barges fare poorly because the waterway infrastructure is so vulnerable to enemy action. Interruption of a single lock or channel can stop the system cold. Similarly, weather affects waterways, diminishing their capacity or prohibiting their use. Only in the interchangeable nature of tugs and barges does an advantage accrue that serves the imperative of continuity. Against the background of these vulnerabilities, logisticians must also consider the responsiveness of the transportation system.

Responsiveness requires that the transport means adapt quickly to changes in priority, both in cargoes and delivery location. Changes in cargo priority is a strength of barge traffic because, like rail cars, preloaded barges can be quickly assembled into tows and dispatched to the destination. Barges in the army inventory can carry nearly any cargo, including refrigerated products.[108] The requirement to change delivery location is less easily met. Obviously, barges must follow the navigable waterways--those clearing the barges' 8 foot draft and wide enough to allow the vessels to maneuver. This places severe limits on the siting of inland terminals which may not serve the commander's needs--especially if he needs to cross a mountain range. Thus the limitations of navigable channels constrain the operational commander in spatial dimensions, and another limitation constrains him in the time dimension.

Depending on the damage incurred, repair times can limit the waterway's responsiveness. Historical data shows how difficult rehabilitating waterways can be. Even during World War II, when the efforts of the entire United States focused on the war, the U.S. Army depended upon host nation support for lock repair and other labor. The Rhine River was opened in September 1945, after five months of work by German contractors and Army engineers.[109] Earlier, Belgians,

---

[106]*FM 55-15*, p. 5-22.
[107]Bykofsky and Larson, pp. 355-356.
[108]*FM 55-15*, p. 5-9.
[109]Bykofsky and Larson, pp. 356-357.

British, and Americans had all labored on the Albert Canal between Antwerp and Liege, taking three months to complete the task.[110] This demonstrates that waterways subjected to ruthless denial operations or to determined interdiction efforts become very difficult to repair. The historical evidence thus indicates that waterways are unresponsive during the operational commander's initial campaign. Given time however, logisticians have often improvised clever means of overcoming such difficulties. Once opened, waterways offer still more opportunities for improvisation.

Waterways allow the transporter the flexibility to adapt his system to varying supply priorities. This is a key aspect of improvisation. In addition to hauling liquid cargo, the army's POL barge can alternatively carry 655 tons of dry cargo on deck.[111] Dry cargo carriers can also carry packaged POL or filled bladders. For example, during the Vietnam War, landing craft shipped POL up rivers to Hue and Dong Ha. These craft were also used to tow barges in other areas when tugs were in short supply.[112] In an extreme situation, full fuel bladders could also be floated behind tow vessels. Though vulnerable to puncture in shallow waters, at least some channels in a theater might allow such operations if the watercraft operators can improvise the necessary towing equipment. In short, functional waterways allow the logistician the flexibility he needs to improvise to meet the operational commander's priorities. This flexibility hinges on a key word--functional.

The overhead associated with operating the waterway stems from several sources. Most formidable is the rehabilitation effort to open the waterways. The other source of overhead is the personnel to operate and secure the watercraft.

The construction and material transport requirements to rehabilitate a waterway are the biggest obstacles to utilizing this means of transport. As noted in the discussion of the continuity and responsiveness criteria, waterways offer an enemy many opportunities to force time-consuming repair on the user. Both denial operations and mining can halt watercraft operations. To meet this challenge, the U.S. Army fields port construction companies which are capable of limited dredging and removal of underwater obstacles.[113] Of three units, only one company is on active duty.[114] Like the planners of 1944, today's logistician looks to host nation or civilian support for clearing waterways. Even with such augmentation, rehabilitation is time consuming, at best.

An example of the resources needed to construct even relatively simple navigation structures is the standard POL mooring for barge loading. This facility is a part of the Army Facilities Components System and consists of some 397 tons of pipe, anchors, and cables. Though simple in

---

[110] Beck, pp. 364-365.
[111] *FM 55-15*, p. 5-9.
[112] Heiser, p. 168
[113] *FM 101-10-2*, p. 3-21.
[114] CACDA, "MTOE to Unit Identification Code Cross Reference," Unpublished file at CACDA Headquarters, 23 January 1990. Hereafter referred to as "CACDA MTOE file."

concept, it requires about 11 weeks for an engineer battalion to construct.[115] Thus, preparing the waterway for military operations is a resource intensive endeavor.

After the waterways are open, operating the watercraft is economical in both fuel and personnel. Tugs consume just over 10 gallons of fuel per hour.[116] With sixteen tugs operating 20 hour days, the modest amount of 3,300 gallons carries the 21st Corps' fuel under average conditions. The personnel requirements are also modest. Each barge is crewed by 4 men and each tug by 11.[117] The fleet then requires around 350 soldiers for both watercraft and command and control. Adding the aforementioned Engineer Port Construction Company and a Military Police Physical Security Company brings the total personnel for this transportation system to just over 700. This is slightly smaller than a mechanized infantry battalion. Thus the efficiency promised by the quote in this section's introduction is fulfilled.

The efficiency in personnel is marred by one problem. The watercraft operating teams to crew the barges and tugs are not in the Army's force structure--either as active units or in the reserve components. These teams exist only on paper, and the experience and training required to operate the craft will be lacking upon any mobilization. Thus the Army appears to be dependent upon host nation support for watercraft and operators as well as for infrastructure repair.

To summarize the analysis of water transport, we note that the "unequalled efficiency and productivity" comes at the expense of anticipation, integration, continuity, and responsiveness. Watercraft are slow and unable to surge POL products on short notice to anticipate the commander's needs. The long lead time necessary to bring a system into operation may preclude its integration into the opening campaign in the theater. Its vulnerability to enemy interdiction denies water transport the promise of continuity. Finally, limited responsiveness in both time and space constrain the commander's use of an otherwise excellent means of transport.

Highway Transport

Highway transport using 5,000 gallon semitrailers is usually the first choice that logisticians consider when planning fuel transport. This is true for a number of reasons. First, Americans are familiar with highway transport as a part of the civilian transportation structure. Through the twentieth century, trucks have carried ever increasing percentages of the nation's freight, reaching 25% in 1980's.[118] Next, the Army has few units operating the alternative transport modes and we have grown accustomed to looking to the Transportation Motor Truck (TMT) units for support in peacetime exercises. Finally, since the tractor-trailers require relatively little infrastructure when compared to barges, rail cars, or pipelines, they are the logical choice for supplying fuel during the first few weeks of a campaign. Their mobility is roughly equal to that of the Combat Service Support

[115] *TM 5-301*, p. 39 and *TM 5-304*, p. A-1.
[116] *FM 55-15*, p. 5-37.
[117] TOE 55-530, p. K15 and L16. *FM 101-10-2*, p. A-59.
[118] Johnson, p. 72.

units within the corps. Therefore, wherever heavy forces go, the convoys of trucks carrying supplies to the corps can follow.

Fueling 21st Corps using only highway trucks is a major undertaking. The system must deliver some 254 truckloads of fuel each day to supply the corps. Using the planning figures of *FM 55-15, Transportation Reference Data,* the corps requires 4 TMT Companies to meets its fuel transport needs at the limit of its advance. Each tractor shuttles trailers along the route for twenty hours each day, covering an average of 20 miles in the hour. At the sustained operational rate of 75% within the truck units, each company operates 45 of its 60 trucks. Command headquarters and trailer transfer point teams round out the system by establishing the required control of the road net.

Most road nets have the required capacity to support this traffic. With a total of 254 loads traversing the net each day, the capacity of a single bituminous surfaced road meets this requirement under average weather and terrain conditions.[119] Only if the corps tried to support itself over a mountain range, in winter, or over a gravel route would a single road prove untenable by virtue of capacity alone. Usually an operational formation will span enough space that it may use several routes, so road capacity is generally no problem except under extreme circumstances. A more likely problem is traffic congestion, which results from locally overloading the road capacity.

The fuel convoys traversing this route do not present a traffic congestion problem by themselves. Assuming the trucks convoy in groups of 15 and use 50 meter intervals, each convoy occupies slightly less than one kilometer of road space. Twelve such columns would be on the road at all times, but when spread over a route in excess of one hundred miles long, congestion will not become a problem. Thus, we may conclude that given the required number of trucks and reasonable road nets, supplying 21st Corps by highway is feasible. We will now examine the mode in terms of the evaluation criteria.

Truck transport allows the logistician several means to surge to meet the operational commander's future needs. The most obvious means is to surge tractor maintenance and operate marginal vehicles on an emergency basis. Given an all-out maintenance effort, planning figures suggest using an 83% operational rate, sustainable for 30 days or less.[120] At this rate, the 21st Corps' truck fleet puts 20 more vehicles on the road and delivers some 1,405,000 gallons daily. Another means to increase the line haul capacity is to divert TMT Companies earmarked for operations within the combat zone. This adds some 90 trucks to the line haul effort, but forces extra loads onto the POL hauling capability of all subordinate units. Cargo carriers can also be diverted to haul 500 gallon "blivets." As a last resort, trucks can be operated 24 hours per day at the expense of crew rest and maintenance, with the predictable results of more accidents and maintenance failures.

Like the other transport modes, tractor trailers offer the logistician little opportunity to anticipate the commander's needs by diverting online storage. Using trailers for storage only takes

[119] *FM 55-15*, p. 3-40.
[120] *FM 101-10-1*, p. 3-2

hauling capacity away from the system, and in this case only around 855,000 gallons is on the road at any one time. This amounts to less than a day of supply and is insufficient to be considered a major stockpile. This requires that the commander and logistician closely integrate their plans.

Highway transport allows close integration with all phases of a campaign. The mobility and flexibility of highway trucks allow them to be integrated immediately with operational plans. But because they share the roads with combat units, the commander must actively manage highway use.

Highway transport's flexibility allows the closest integration with tactical plans during the opening phases of a campaign. Since the tractors-trailer combinations can traverse most roads in the wake of combat engineers, neither long lead times nor exceptional resources are needed to operate a truck transport system within a theater. The truck system is ready immediately upon the arrival of the first TMT unit in the theater. This allows them to deliver fuel while other mode's infrastructures are still under repair. Still, the road net requires constant maintenance even after its initial repair. Since combat engineer units accomplish the initial repairs, specialized units are not required. Thus good mobility allows motor trucks to meet the corps' initial needs for fuel transport. As more units arrive in theater, close integration with the operational plan becomes more important with increasing traffic density.

Traffic congestion is one major problem with placing extra burdens on the highway system. Fuel hauling trucks compete for road use with transport units hauling other supplies as well as unit deployments. In some theaters, civilian traffic may also burden the road network. Therefore, fuel convoys need to be thoroughly integrated with other highway users. Tractor operators and supervisors must stringently enforce movement orders and discipline to insure a steady, continuous flow of fuel to the combat units.

To summarize, there are two ways that highway transport meets the criterion of integration. First, highways are the least difficult to repair of all transportation infrastructures, allowing logisticians to operate trucks immediately upon entering the theater. Secondly, the need to intensely manage the highway movements forces the commander to provide for this integration to avoid gridlock.

The highway transport system meets the criterion of continuity through redundancy. First, it is less sensitive to enemy attack than other modes. Next, the sheer numbers of trucks provide their own maintenance backup. In contrast, combinations of weather and terrain present major obstacles to the systems' continuity.

The highway transport system as a whole is less vulnerable to enemy attack than other modes. Although single convoys and vehicles are vulnerable to attack, the destruction of one convoy fails to completely unhinge the system as with other modes. Each tractor-trailer represents about $^1/_{170}$th of the transport system. This recall's Clausewitz's dictum that convoys are low payoff targets.[121] A higher

[121]Clausewitz, p. 555.

payoff target is the road network itself. Here sabotage can destroy a bridge or tunnel with relative ease, although this loss is generally less significant than losing a railroad bridge. Tactical or improvised bridging may quickly replace a highway bridge designed to carry 40 ton fuel trucks, while rebuilding a rail bridge to support a 120 ton locomotive is more difficult. During repairs, truck traffic bypasses obstacles more easily, allowing support operations to continue. Thus, the redundancy of road nets and the numbers of tractors provide the system with a measure of continuity.

Mechanical failures also create less impact because of the numbers of prime movers. Since tractors are high density items with common repair parts, and because one tractor represents such a small part of the overall system, mechanical failures of individual tractors have little impact on the system. When one tractor breaks, one (hopefully) is repaired. Also, reduced operational rates are built into the planning figures giving a realistic appreciation for unit capabilities from the outset. Nevertheless, cumulative losses over time eventually degrade the capacity of the transport system. In sum, under good road and weather conditions, highway transport has the potential for good continuity.

Weather affects the system by slowing traffic, reducing the capacity of roads, and stopping it altogether in extreme conditions. While rains slow traffic on any road, non-paved surfaces quickly deteriorate when subjected to combinations of heavy traffic loads and wet subgrades. The results are increased repair requirements, slowed traffic, and potential washouts. Under such conditions, increased wear on vehicles results and tractors may not be able to pull full loads. German commanders learned these lessons the hard way during the 1941 Russian campaign, when autumn rains turned the steppes into a morass and nearly brought their formations to a standstill.[122] Thus weather is the potential adversary of the highway system calling its continuity to question, especially in theaters having relatively undeveloped road networks. Weather indirectly affects the system's responsiveness, too.

Highway transport meets the criteria of responsiveness primarily through its flexibility. Tractor-trailer combinations can respond to changes in load priority. They can also mass for specific priority missions and quickly respond to changes in destination.

The flexibility of truck transport allows it to respond quickly to the operational commander's changing product or location needs. Since tractors hauling tank semitrailers can also haul van or flatbed semitrailers, the same tractors and crews can divert to hauling other products if these trailers are available. This allows altering the mix of supplies delivered forward in response to the changing needs of the operational commander. Since trucks can go nearly anywhere a fighting division operates, they can deliver these supplies to remote areas without changes in transport mode and the resultant double handling. Thus the minimal infrastructure requirements mean that highway transport

[122]Martin Van Creveld, *Supplying War*, Cambridge University Press, Cambridge, 1977, pp. 171-172.

stands the best chance of following the theater combat forces and constrains the operational commander least in his choice of lines of operations.

To summarize, truck transport operations quickly respond to changes in the main effort or changing line of operations. The flexibility and minimal construction effort required to support highway operations makes them the most responsive to the operational commander in terms of product priority, space, and time.

Situations sometimes demand that the logistician improvise to meet supply requirements using the means at hand. They need to adapt a means to new priorities or simply make it do something for which it was not designed. In terms of highway transportation, improvisation takes the shape of using ad hoc organizations, host nation trucks, or expedient means to increase capacity of the system. History provides a spectacular example of improvisation to meet operational supply priorities using highway transport.

Described as "largely an impromptu affair,"[123] the Red Ball Express was an improvisation on a grand scale designed to supply the rapidly advancing U.S. Armies in France. Planned in the space of two days between 23 and 25 August 1944, it quickly reached its peak capability of 12,342 tons on August 29.[124] Much of this tonnage was gasoline. During its two and a half month life, the express service delivered about 412,000 tons of supplies to the First and Third U.S. Armies, averaging 5,000 tons per day.[125] Red Ball was a system consisting of nearly 6,000 trucks gleaned from every unit in the Communications Zone, operating over a one way loop of highways. This was an improvisation for two reasons. First, because it was a large scale, centralized operation that circumvented doctrinal transport procedures. Secondly, because trucks were taken from every source--actual transportation units, combat support units like artillery and engineers, as well as trucks from the supply system, which were placed in the hands of troop replacements who had little or no driver training.[126] The system itself consumed some 300,000 gallons of gasoline daily. The long term costs of sustained operations were greatly increased need for truck repairs and parts. By the end of September, the number of major repairs needed on the truck fleet reached 5,750.[127] Truck tire use in the theater nearly doubled between August and September with usage rocketing from 29,000 to over 55,000 tires.[128] Even the well-equipped armies of the Normandy campaign could not sustain such an all-out effort as the Red Ball Express. It successfully extended the length of the fighting units' lines of communications, but its terrible cost indicated that it was a short term improvisation at best.

In other theaters, army transporters resorted to less spectacular improvisations. During Operation Torch in North Africa, authorities requisitioned civilian trucks in both Oran and

---

[123]Ruppenthal, p. 569.
[124]Ibid. p. 560.
[125]Bykofsky and Larson, p. 334.
[126]Ibid. p. 335, also Ruppenthal, p. 570.
[127]Ruppenthal, p 571.
[128]Ibid.

Casablanca. In Oran, the major supplier was a wine syndicate which supplied some 380 charcoal-burning trucks.[129] Another expedient used in North Africa was backhauling one-ton trailers in the cargo beds of trucks, enabling more trailers to be carried and saving wear.[130] Today, transporters routinely plan to stack flatbed semitrailers top to top for backhaul.[131]

Other expedients are available to the logisticians to increase the transport system's capacity. In addition to stacking flatbeds, they can stack tractors or tank trailers on flatbeds, although the time and trouble involved is justified only for long hauls. If the highways are in good condition and are flat, single tractors can tow two trailers by using a fifth wheel dolly to support the second trailer. Finally, cargo trucks can carry POL in bladders or expedient tanks. Thus highway transport lends itself readily to improvisation. This flexibility comes at the expense of a large overhead, however.

Highway transport to serve the 21st Corps' fuel needs requires the largest overhead of any transport mode. This overhead comes in terms of unit deployments, personnel, and finally by fuel consumption by the trucks themselves.

In addition to the four TMT companies which physically haul the fuel, several units and teams provide vital services to the transport system. At least one command and control headquarters (TOE 55-16) organizes the TMT companies, and at least two Trailer Transfer Point Teams run the required trailer transfer points (TOE 55-540, Team GE).[132] Other requirements include a Physical Security Company (TOE 19-97) for security and Engineer Combat Heavy Battalion (TOE 5-115) for route maintenance.[133] The estimate of normal route repair requirements is somewhat short of the engineer battalion's 1000 man-hour per day capacity, however, these requirements could increase greatly based on an active enemy. In sum, the two battalion-sized and separate units aggregate to some 1775 soldiers--equivalent to more than two mechanized infantry battalions.

The fuel used by this transport system is also a significant overhead. Although a bulk fuel summary for the truck companies and combat heavy engineer battalion aren't available in the FM 101-10-1 panning figures, we may use summaries from similar units for rough estimates. Using planning figures for the heavy division's TMT Company and engineer battalion to estimate this force's fuel needs, we find that the four TMT companies will likely use around 45,000 gallons with the engineer battalion requiring about 24,000 gallons. Thus some 69,000 gallons of fuel must be added to the corps' daily requirement, bringing it to 1,339,000 gallons. The fuel transport system then requires about 5% of the total fuel used by the corps. Looking at this another way, the fuel trucks alone consume more JP8 than the airborne division.

[129]Bykofsky and Larson, p. 162.
[130]Ibid. p. 163.
[131]*FM 55-30, Army Motor Transport Operations*, Department of the Army, Washington, 1980, p.4-9.
[132]*FM 101-10-2*, pp. 27-4 to 27-6, p. 27-39.
[133]Ibid. p. 14-3, *FM 101-10-1*, p. 1-46, and *TM 5-304*, p. A-1.

Overhead is a chief disadvantage of truck transport. It requires the largest forces and most fuel of any mode to deliver 1,270,000 gallons of fuel to the 21st Corps. Performing this one transport function requires personnel equivalent to two infantry battalions, nearly 250 tractor-trailers, and consumes 69,000 gallons of precious fuel each day.

In the overview, truck transport has many advantages that make is attractive to the operational commander and his logisticians. First of all, it has some ability to surge in anticipation of future needs by exploiting various means to put more trucks on the road. It allows the commander to integrate transport with every phase of his operation, as it will function beginning with the first truck unit reaching the theater. No exceptional resources or long lead times are necessary. The very number of the prime movers and the redundancy of most road nets make individual trucks and road structures less productive targets for enemy activity, though cumulative damage could be inflicted over time by a determined enemy. Of all transport modes, this one is most responsive to the commander by having the potential to place supplies anywhere on the road net he wants them without lengthy reconstruction of railroad tracks, canals, or pipelines. Finally, it offers great potential for improvisation. Both adapting army trucks to other purposes and using requisitioned trucks are expedients with which transporters are familiar.

The chief disadvantage of highway transport is its low capacity relative to overhead. The 21st Corps needs twice as many men, more fuel, and 250 more trucks to haul its fuel when using highway transport instead of other means. Though the overhead is much less than that of the 1944 Red Ball Express, it shows that now as in 1944, the capacity of trucks makes them at best uneconomical, and in some terrain, an infeasible means of supporting the fuel needs of operational formations.

Conclusion

Several conclusions may be drawn from the analysis of the transportation modes presented in this monograph. These may be categorized as: observations on our doctrine's link with theory, implications for campaign planning, and comments on mixed mode operations. Each of these broad areas impacts on the problem of fueling operational maneuver.

Our Army's maneuver doctrine embraces five sustainment imperatives. These are anticipation, integration, continuity, responsiveness, and improvisation. They are all desirable characteristics of a sustainment system, but another of equal importance was included in this analysis--minimizing overhead. Clearly, a sustainment operation becomes self-defeating if it consumes as many resources as it provides to the fighting forces. Examples of fuel transport from World War II indicate that such situations occurred on several occasions. Therefore our doctrine should also stress economy in building the sustainment system within a theater. One way to begin is to add this concept to the sustainment imperatives in our doctrinal manuals.

Another doctrinal issue was stated by the basic research question--By what means should the Army's theater sustainment structure provide fuel to a corps in an immature theater? The analysis

indicates that current Army doctrine emphasizing pipelines as the mainstay of a multiple mode fuel transport system is correct for today's force structure. It establishes responsibility and priority for preparing POL related infrastructures. It also advocates support operations phased in time and staged in distance. Historical evidence indicates that the priority and responsibility issues are essential to force planning. The evidence also show that preplanned phasing and staging are critical to planning successful campaigns.

Several implications for campaign planning arise in this monograph. The first is that transportation hubs and lines of operation should be considered when choosing operational objectives. The second is that logisticians involved in campaign planning have difficulty predicting requirements for transporting fuel in theaters currently held by the enemy. Next, security and positive control are both essential within the rear area. Finally, using all available transport modes in a phased sustainment operation holds promise for successful campaigns. Each is discussed in turn.

At the operational level, sustainment considerations may dictate the objectives of campaigns and major combat operations. FM 100-5 states that major operations may be mounted to "secure lines of communication required to support subsequent phases of a campaign." This statement fails to communicate the importance of logistical infrastructures to the campaign. Jomini observed that rivers are the "most favorable" lines of operation for armies of his day.[134] In a similar fashion, lines of support may dictate lines of operation for heavy forces today. Likewise, critical transportation hubs may become the principal focus of effort for the operational commander because of their important role in consolidating the present campaign or basing a subsequent one. Once the operational commander has determined his objective however, his logistic planners' work has only begun.

Estimating the supply requirements for operations in areas that are currently held by the enemy is a difficult and imprecise undertaking. Using fuel transport as an example, the logistician has only a very general idea of when the various transport means may be put into operation and what resources they will require as a result of war damage. Uncertainty from rehabilitating the infrastructure compounds the uncertainty from choosing economical methods of intratheater fuel transport.

Another issue confronting the campaign planner is security of the lines of communications. Security is essential to operating any fuel transport mode. This analysis identifies a security force as part of the required overhead for each mode because hostile partisan activity can prevent an otherwise adequate system from delivering sufficient fuel. Likewise, air superiority is vital to protecting lumbering fuel trains, barges, and convoys. Assets used to secure these transportation assets are really conducting an economy of force operation, because the commodities they carry are so essential to combat operations. Simply put, the commander cannot fail to protect them--his decision is one of how much to devote to their security, not whether he will secure them.

---

[134]Jomini, p. 145.

In addition to protecting the transport means, the commander must also provide for their control. Control ensures more efficient use of the assets, and in the case of highway transport ensures that the highway net is available for movement of combat forces. Not only must the logistician bring adequate transportation headquarters and traffic control teams into the theater, he must also attend to such mundane details as road signs. Insufficient road signs, combined with a nonfunctional telephone system wasted many man-hours and truck-miles in Oran in 1943.[135] This emphasizes that a transportation system is more than just the pipes, barges, or trucks. People trained in its control and skilled in planning its utilization are needed within the theater.

Opening transportation modes by phase within the theater worked well for the Allies in both North Africa and Normandy. Although many transport means, including airlift were eventually used in the theaters, initial haul requirements were met by highway trucks. As transport requirements increased, the load was shifted to higher capacity modes which were gradually becoming operational over wider areas. Thus the phasing was accomplished in both time and space, and utilized the modes in a complementary fashion. Our current transportation doctrine advocates this approach. This highlights the need for synchronizing all available modes of transport.

Hybrid transportation systems utilizing pipelines, rails, waterways, and highways meet the needs of the campaign planner better than any single mode system. Multimode operations allow the logistician to capitalize on the strengths of one mode to offset the weaknesses of another much as the tactician plans mutual support during combined arms operations. The capacity of rails and pipelines may be complemented with the economy of water transport and flexibility of highways. The following example of a hybrid system illustrates this point. A relatively short pipeline could be built over a mountain pass between areas where railways are available. Faced with the choice of sending tractor trailers over twisting, poor quality roads, or building a pipeline, the logistician chooses the pipeline on the basis of its superior capacity and all weather operation. This simple example illustrates the idea that advantages of some modes may offset disadvantages with others. Thus a multimode system provides the greatest flexibility and capacity.

Any system, whether designed to be single or multimode relies on highways to some extent. Trucks are vital to any fuel transport operation for several reasons. First, they are the primary resupply means within the combat zone, eventually entering the picture anyway. Next, they give flexibility to other transport means by providing links between railhead or inland water terminal and the eventual destination. Since railroad and waterway terminal locations are fixed at sites that may not efficiently serve the operational commander's needs, trucks play a vital role in extending the transportation system.

A training and force structure issue also arises from the analysis. This issue is that our army lacks the specialized personnel to operate multimode transportation systems--especially railways and waterways. Since few watercraft and no railway units are on active duty, initial operations in a

---

[135]Bykofsky and Larson , p. 162.

theater will probably be completed before these specialized units are deployed. Even so, the few units in the reserve components will not allow the army to undertake large scale transport operations without drafting skilled people or providing lengthy training. The U.S. thus depends upon host nations whose governments may be uncooperative or whose support may be unreliable for vital transportation services overseas.

To summarize, each transport mode analyzed has strengths that may offset weaknesses of other modes. Thus the best means for the theater sustainment structure to provide fuel to a corps in an immature theater is to utilize all available means. This begins with the campaign plan. It requires planning rehabilitation efforts by engineers and contractors, utilizing host nation personnel for rail and waterway operations, and constructing pipelines where capacity and terrain warrant. Fuel transport is a vital part of campaign planning--and it's too important to be left to the quartermaster alone.

<u>Bibliography</u>

<u>Books</u>

Beck, Alfred M., Abe Bortz, Charles W. Lynch, Lida Mayo, and Ralph F. Weld. *United States Army in World War II. The Technical Services: The Corps of Engineers. The War Against Germany.* Washington, D.C.: Center of Military History, 1985.

Bykofsky, Joseph and Harold Larson. *United States Army in World War II. The Technical Services: The Transportation Corps: Operations Overseas.* Washington, D.C.: Center of Military History, 1957.

von Clausewitz, Carl. *On War.* Princeton, N.J.: Princeton University Press, 1984.

Coll, Blanche D., Jean E. Kearth, and Herbert H. Rosenthal. *United States Army in World War II. The Technical Services: The Corps of Engineers. Troops and Equipment.* Washington, D.C.: Office of the Chief of Military History, 1958.

Goralski, Robert and Russell W. Freeburg. *Oil in War.* New York: William Morrow and Company, 1987.

Heiser, Joseph M. Jr. *Logistic Support: Vietnam Studies.* Washington, D.C.: Department of the Army, 1974.

Huston, James A. *The Sinews of War: Army Logistics 1775-1953.* Washington, D.C.: Government Printing Office, 1966.

Johnson, Otto, editor. *The 1990 Information Please Almanac.* Boston: Houghton Mifflin Company, 1989.

Jomini, Antoine Henri. *The Art of War.* Westport, Connecticut: Greenwood Press, 1977.

Ruppenthal, Roland. *Logistical Support of the Armies. Volumes I and II.* Washington, D.C.: Office of the Chief of Military History, 1954.

Sun Tzu. *The Art of War.* London: Oxford University Press, London, 1963.

Triandafillov, V.K. *Nature of Operations of Modern Armies.* Moscow: State Publishing House, 1929, (Translation by Russ-Eng Translations, Inc.).

Tukhachevskiy, Mikhail. *New Problems in Warfare.* Carlisle Barracks, PA: U.S. Army War College, 1983, (Reprint by Art of War Colloquium).

Van Creveld, Martin. *Supplying War: Logistics from Wallenstein to Patton.* London: Cambridge University Press, 1977.

<u>Manuals and Pamphlets</u>

Field Manual 10-67, Petroleum Supply in Theaters of Operations. Washington, D.C.: Department of the Army, 1985.

Field Manual 10-69, Petroleum Supply Point Equipment and Operations. Washington, D.C.: Department of the Army, 1982.

Field Manual 55-15, Transportation Reference Data. Washington, D.C.: Department of the Army, 1986.

Field Manual 55-20, Army Rail Transport Operations and Units. Washington, D.C.: Department of the Army, 1988.

Field Manual 55-30, Army Motor Transport Units and Operations. Washington, D.C.: Department of the Army, 1980.

Field Manual 55-50, Army Water Transport Operations. Washington, D.C.: Department of the Army, 1985.

Field Manual 100-5, Operations. Washington, D.C.: Department of the Army, 1986.

Field Manual 100-10, Combat Service Support. Washington, D.C.: Department of the Army, 1988.

Field Manual 100-15, Corps Operations. Washington, D.C.: Department of the Army, 1989.

Field Manual 100-16, Support Operations: Echelons Above Corps. Washington, D.C.: Department of the Army, 1985.

Field Manual 101-10-1, Staff Officer's Field Manual Organizational Technical and Logistical Data Planning Factors. Washington, D.C.: Department of the Army, 1987.

Field Manual 101-10-2, Extracts of Non-Divisional TOE. Washington, D.C.: Department of the Army, 1977.

Field Manual 700-80, Logistics. Washington, D.C.: Department of the Army, 1982.

Field Manual 701-58, Planning Logistic Support for Military Operations. Washington, D.C.: Department of the Army, 1982.

TOE 55-530, Transportation Watercraft Teams. Washington, D.C.: Department of the Army, 1989.

Technical Manual 5-301, Army Facilities Components System--Planning. Washington,D.C.: Department of the Army, 1979.

Technical Manual 5-304, Army Facilities Components System---User Guide. Washington, D.C.: Department of the Army, 1979.

Technical Manual 5-343, Military Petroleum Pipeline Systems. Washington, D.C.: Department of the Army, 1969.

TRADOC Pamphlet 11-9, (Draft), Blueprint of the Battlefield. Ft. Monroe, Virginia: U.S. Army Training and Doctrine Command, 9 June 1989.

<u>Periodicals</u>

Bacle, Urson S. "Trans-Korea Pipeline Modernization: An Update," *Army Logistician*, March-April 1988, pp. 27-28.

Bradley, Gary W. "The Trans-Korea Pipeline: Will There Be Enough Fuel?" *Army Logistician*, November-December 1987, pp. 2-6.

Brinkley, William A. "The Cost Across the FLOT," *Military Review*, September 1986, pp. 30-41.

Cutler, Tom. "Myths of Military Oil Supply Vulnerability," *Armed Forces Journal International*, July 1989, pp. 43-49.

Dacey, Richard P. and Gregory J. Rosenthal. "The Single Fuel Battlefield," *Army Logistician*, January-February 1989, pp. 2-5.

Fast, William R. "Operational Level Support: In Search of Doctrine," *Military Review*, February 1988, pp. 46-52.

Gorczynski, David, and David Auman. "Engineer Troops on a Pipeline Exercise," *Military Engineer*, January-February 1988, pp. 74-78.

Hofman, A. J. Th. "The Central European Pipeline System: Another Form of Transport," *Defense Transportation Journal*, June 1983, pp. 31-33.

Jeffries, Lewis I. "U.S. Railroads: A Forgotten Military Asset," *Military Review*, February 1986, pp. 49-57.

Kitfield, James and James Russel. "Can Trucks Keep Up With Army Doctrine:" *Military Logistics Forum*, June 1986, pp. 48-51.

Metz, Robert W. "Military Pipeline Operations," *Engineer*, Spring 1987, pp. 16-18.

McHenry, Robert W. "Petroleum Support for REFORGER," *Army Logistician*, November-December 1989, pp. 12-14.

Odorizzi, Charles D. "Can the Army's Tail Keep Up With Its Tooth?" *Armed Forces Journal International*, July 1986, pp. 60-68.

Rodon, Raymond L. "Lifeline to Sustainment: The European Military Pipeline System," *Quartermaster Professional Bulletin*, Summer 1989, pp. 5-7.

Rosenburgh, Bob. "Testing the Petroleum Pipeline," *Army Logistician*, May-June 1987, pp. 16-17.

Sullivan, Bloomer D. "Logistical Support for the AirLand Battle." *Military Review*, February 1984, pp. 3-16.

Wheeler, Albin G. "Operational Logistics in Support of the Deep Attack." *Military Review*, February 1986. pp. 13-19.

Wright, James E. and Charles C. Perry. "Cold Weather POL Operations." *Army Logistician*, May-June 1986, pp. 34-38.

Woolstrum, Michael. "Bulk Fuel Operations in Gallant Eagle," *Army Logistician*, July-August 1987, pp. 8-9.

Zimmerman, Douglas K. "Can a U.S. Army Corps Support Itself in War?" *Military Review*, February 1988, pp. 30-39.

Monographs, Reports and Other Unpublished Sources

Cannon, Charles C. Jr. "Combat Service Support of AirLand Battle Doctrine," Research Monograph. Ft. Leavenworth: U.S. Army Command and General Staff College, 1986.

Dail, Robert T. "Does the U.S. Army Really Understand Operational War?--A Logistics Perspective." Research Monograph. Ft. Leavenworth: U.S. Army Command and General Staff College, 1988.

Harmon, Larry D. "Scavenger Logistics in Support of Tactical Operations." Research Monograph. Ft. Leavenworth: U.S. Army Command and General Staff College, 1986.

Idiart, Philip L. "Sustainment in a Secondary Theater: An Analysis of the Effect of Transportation on Campaign Execution in North Africa, 1941-42, and Its Relevance to Southwest Asia." Research Monograph. Ft. Leavenworth: U.S. Army Command and General Staff College, 1987.

Krysa, John C. "Operational Planning in the Normandy Campaign, 1944." Research Monograph. Ft. Leavenworth: U.S. Army Command and General Staff College, 1988.

Nichols, Howard V. "Operational Level Logistics: An Examination of the U.S. Army Logistics Doctrine for the Operational Level of War." MMAS Thesis. Ft. Leavenworth: U.S. Army Command and General Staff College, 1984.

Privratsky, Kenneth L. "British Combat Service Support During the Falkland Islands War: Considerations for Providing Operational Sustainment to Remote Areas,." Research Monograph. Ft. Leavenworth: U.S. Army Command and General Staff College, 1986.

Rockwell, Christopher A. "Operational Sustainment, Lines of Communication and the Conduct of Operations." Research Monograph. Ft. Leavenworth: U.S. Army Command and General Staff College, 1987.

Schneider, James J. "Theoretical Paper Number Three." School of Advanced Military Studies, Ft. Leavenworth, Kansas, 1988.

Smith, Bradley F. "The Role of Army Railroading at the Operational Level of War." Research Monograph. Ft. Leavenworth: U.S. Army Command and General Staff College, 1989.

Tosch, David F. "Sustaining Tactical Maneuver on the AirLand Battlefield: Will the Current Support Concept for Supplying Fuel Provide the Means?" Research Monograph. Ft. Leavenworth: U.S. Army Command and General Staff College, 1986.

----------. "German Operations in North Africa: A Case Study of the Link between Operational Design and Sustainment" Research Monograph. Ft. Leavenworth: U.S. Army Command and General Staff College, 1987.

Wehner, Randolph B. "Sustainment Improvisation-Expanding the Realm of the Possible." Research Monograph. Ft. Leavenworth: U.S. Army Command and General Staff College, 1987.

CACDA, "MTOE to Unit Identification Code Cross Reference," Unpublished file at CACDA Headquarters, 23 January 1990.

Appendix A: Troop List of 21st (US) Corps

Unit	TOE	Strength	Deploying	Unit Fuel Consumption	TOE based
HHC, 21st Corps	52-2H410	331		2,542	
55th Mech Div	87-000J440	17330	*	629,415	•
47th Air Assault Division	67-000L	15757	*	278,048	•
102d Airborne Division	57-000L	12939	*	44,655	•
21st Aviation Brigade	01-400L	300	*	2,304	
Atk Helo Bns. (6 ea.)	01-385L	1692	*	101,503	•
Aslt. Helo Bns. (2 ea.)	01-205L	700	*	55,454	•
Med. Helo Bn. (CH-47)	01-245L	680	*	68,158	•
Cmd Avn Bn.	01-4151	363	*	16,683	•
230th Separate Armored Brigade	87-100J430	4209	*	133,133	•
780th Ranger Bn	7-85H	604	*	4,638	
21st Corps Artillery	06-501H200	199	*	1,528	
1-206 (Lance) FA	06-595H	441	*	3,386	
1-602 (105,T) FA	06-405H400	455	*	3,494	
2-607 (203,SP) FA	06-445J	492	*	8,388	•
2-608 (203,SP) FA	06-445J	492	*	8,388	•
2-609 (203,SP) FA	06-445J	492	*	8,388	•
2-610 (203,SP) FA	06-445J	492	*	8,388	•
2-632 (155,SP) FA	06-455H	513	*	8,388	•
2-633 (155,SP) FA	06-455H	513	*	8,388	•
2-675 (MLRS) FA	06-525J	461	*	7,326	•
21st ADA Bde	44-002	139		1,067	
1-430 (Chap) ADA	44-725	575	*	4,415	
1-461 (Hawk) ADA	44-395J400	555	*	4,262	
1-462 (Hawk) ADA	44-395J400	555		4,262	
1-463 (Hawk) ADA	44-395J400	555		4,262	
1-500 (Patriot) ADA	44-635J100	798		6,128	
750th ADA Sig Op Co				0	
21st Engr Bde (Corps)	05-101	127	*	975	
500th Engr Cbt Bn (Corps)	05-35H	775	*	5,951	
502d Engr Cbt Bn (Corps)	05-35H	775	*	5,951	
538th Engr Cbt Bn (Abn)	05-195H	656	*	5,037	
5005th Engr LE Co (Abn)	05-54H	207	*	1,590	
5080th Engr Cbt Spt Equip Co	05-58H	227	*	1,743	
21st MI Bde (CEWI)	34-202J	47	*	361	
221st MI Bn (Op)	34-105J	588	*	4,515	
211th MI Bn (Tac Xplt)	34-125J	573	*	4,400	
201st MI BN (Aerial Xplt)	34-145J	410		3,148	
				0	
21st Sig Bde (Corps)	11-400L	2403	*	18,453	
				0	
21st COSCOM				0	
HHC, COSCOM	54-22H	376		2,887	
2423d DPU (COSCOM)	29-550T	114		875	
2003d MMC (COSCOM)	54-23H	425		3,264	
4106th MMC (COSCOM)	55-6H	70		538	
HHD, 83d Med Gp	8-122H	52		399	
846th MEDSOM Unit	8-287H	165	*	1,267	
814th CSH	8-123J	440		3,379	
815th CSH	8-123J	440		3,379	
84th MASH	8-63H	239	*	1,835	
85th MASH	8-63H	239	*	1,835	
HHD, 801st Med Bn	8-126H	39		299	
855th Med Amb Co.	8-127H	107	*	822	
857th Med Amb Co.	8-127H	107	*	822	

851st Med Air Amb Co	8-137H	194	*	1,490
867th Med Clr Co	8-128H	140	*	1,075
HHD, 802st Med Bn	8-126H	39		299
859th Med Amb Co.	8-127H	107	*	822
860th Med Amb Co.	8-127H	107	*	822
868th Med Clr Co	8-128H	140	*	1,075
HHC, 16th Spt Gp	29-102H	90	*	691
HHD, 23d S&S Bn	29-146H	70	*	538
206th S&S Co (DS)	29-147H	251	*	1,927
207th S&S Co (DS)	29-147H	251	*	1,927
225th Fld Svc Co (GS) (Fwd)	29-114H	122	*	937
226th Fld Svc Co (GS) (Fwd)	29-114H	122	*	937
HHD, 95th Maint Bn (DS/GS)	29-136H	59	*	453
907th Maint Co (Rr) (DS)	29-208H	274	*	2,104
915th Lt Maint Co (Fwd)(DS)	29-207H	228	*	1,751
916th Lt Maint Co (Fwd)(DS)	29-207H	228	*	1,751
702d TAMC (AVIM)	55-459J	322	*	2,473
HHC, 17th Spt Gp.	29-102H	90		691
HHD, 21st S&S Bn	29-146H	70		538
213th S&S Co (DS)	29-147H	251		1,927
214th S&S Co (DS)	29-147H	251		1,927
227th Fld Svc Co (GS) (Fwd)	29-114H	122		937
HHD, 96th Maint Bn (DS/GS)	29-136H	59		453
906th Maint Co (Rr) (DS)	29-208H	274		2,104
917th Lt Maint Co (Fwd)(DS)	29-207H	228		1,751
918th Lt Maint Co (Fwd)(DS)	29-207H	228		1,751
703d TAMC (AVIM)	55-459J	322		2,473
HHD, 70th TMT Gp	55-12H	61		468
HHD, 772d TMT BN	55-16H	50		384
712th Trans Mdm Trk Co (Cntnr/Cgo)	55-18H	186	*	1,428
730th Trans Hv Trk Co	55-28H	152	*	1,167
735th Trans Lt-Mdm Trk Co	55-67J	185	*	1,421
718th Trans Mdm Trk Co (Water)	55-18H	184	*	1,413
719th Trans Mdm Trk Co (Water)	55-18H	184	*	1,413
755th Trans Tml Trf Co	55-118J	250		1,920
757th Trans TS Co (Break Bulk)	55-117H	330		2,534
7027th Trans TS Co (Cntnr)	55-124J	296		2,273
HHD 33d Petrl Sup Bn	10-226H	54	*	415
258th Petrl Sup CO	10-227H	189	*	1,451
721st Trans Mdm Trk Co (Petrl)	55-18H	176	*	1,352
722d Trans Mdm Trk Co (Petrl)	55-18H	176	*	1,352
HHD, 56th Ammo Bn (Convl)(DS/GS)	9-66J	67	*	514
508th Ord Convl Ammo Co (DS)	9-64H	210	*	1,613
514th Ord Sp Ammo Co (DS)	9-84H	217		1,666
530th EOD Con Cen Tm	9-520H(AA)	11	*	84
EOD [illegible]	9-520H(FA)	30	*	230
365th [illegible] Scty Co	19-97H	141	*	1,083
HHD, 24th S&S Bn	29-146H	70		538
239th Gen Sup Co (GS)	29-118H	202		1,551
249th Rep Parts Sup Co (GS) (Corps)	29-129H	179		1,375
254th Acft &Msl Rep Parts Sup Co (GS)	29-129H	179		1,375
2258th Ldry & Renv Co (GS)	10-437H	148		1,137
2259th Ldry & Renv Co (GS)	10-437H	148		1,137
HHD, 11th P & A Bn	12-66H	58		445
102d PSC (Type D)	12-67H	199	*	1,528
103d PSC (Type D)	12-67H	199		1,528
HHD, 803d Med Bn	8-126H	39		299
816th CSH	8-123J	440		3,379

817th CSH	8-123J	440	3,379
837th Evac Hosp	8-581J	548	4,208
838th Evac Hosp	8-581J	548	4,208
Total Corps Strength		83418	1,354,709
Strength Not Deploying	11080		
Consumption Rates:			
Per person: (in lb/day)	53.7		
POL Intensive (TOE Base)			
Total Corps Consumption			
Not Deploying		85,084	
Deploying Population Based		109,942	
Deploying Unit based		1,159,683	
Total Corps Consumption (Dual Based)		1,354,709	
To be transported (gallons)		1,269,625	

Terminal Installation 200,000 barrel	Quantity	Weight	Individual Facilities: Shipping Weight	Individual Facilities: Labor Requirements Horiz	Vert	Unskilled	Installation Total: Shipping Weight	Installation Total: Labor Requirements Horiz	Vert	Unskilled
		ston	meas. ton	man-hours by category			meas. ton	man-hours by category		
Mooring, tanker 60' depth	1	67	79	480	520	310	79	480	520	310
Pipe & Accessories, 12", 1 mi	4	45	185	40	950	420	740	160	3800	1680
Pipeline, submarine 2750'	1	91	120	1800	2180	200	120	1800	2180	200
Pump fuel supply, 4 unit	4	1	1	8	52	20	4	32	208	80
Pump, booster 7000 BPH	4	25	47	40	280	80	188	160	1120	320
Tank, 4" line, 250 bbl	3	13	25	100	45		75	300	135	0
Tank Farm Installation consisting of:										
Flood pump & manifold, 1355 bbl.	2	15	17	20	360	100	34	40	720	200
Manifold, switching	1	26	30	240	80	60	30	240	80	60
Pipe & acc., API 12", 1000'	6	24	40	10	230	160	240	60	1380	960
Pipe & acc., API, 8", 1000'	0.2	13	20	10	200	140	4	2	40	28
Pipe & Acc., tubing, 12",1000'	1	9	40	15	195	71	40	15	195	71
Pump fuel supply, 2 unit	2	1	1	5	35	20	2	10	70	40
Tank Pump & Manifold, 2800 bbl.	4	7	12	5	40	15	48	20	160	60
Tank, 12" lines, 10000 bbl	19	46	73	140	850	430	1387	2660	16150	8170
Tank, 8" lines, 3000 bbl	4	19	33	90	310	220	132	360	1240	880
Tank, water, 1,000 bbl	1	12	13	80	320	130	13	80	320	130
Transfer pump & manifold 2800 bbl.	1	19	22	45	345	70	22	4[illegible]	345	70
				Terminal Total			3158	6464	28663	13259

Trunk Pipeline System										
135 miles, 9 pump stations			Individual Facilities:				Installation Total			
3 intermediate terminals	Quantity	Weight	Shipping	Labor Requirements			Shipping	Labor Requirements		
Description			Weight	Horiz	Vert	Unskilled	Weight	Horiz	Vert	Unskilled
		ston	meas. ton	man-hours by category			meas. ton	man-hours by category		
Collapsible tanks 50K	21	8	17	10	55	15	357	210	1155	315
Flood pump,1355BPH	1	10	14	20	280	80	14	20	280	80
Pump fuel supply, 4 unit	9	1	1	8	52	20	9	72	468	180
Pump station, 8"	9	28	51	40	240	110	459	360	2160	990
Suspension bridge, 200"	10	2	8	0	55	50	80	0	550	500
Tubing, 8", 5 mile	27	135	434	50	1550	1060	11718	1350	41850	28620
				Pipeline Total			12637	2012	46463	30685

			Individual Facilities					Installation Total		
Barge Loading Facilities	Quantity	Weight	Shipping	Labor Requirements			Shipping	Labor Requirements		
300,000 gallon			Weight	Horiz	Vert	Unskilled	Weight	Horiz	Vert	Unskilled
Installation QA 1205		ston	meas. ton	man-hours by category			meas. ton	man-hours by category		
Booster station, 1400BPH	2	11	21	58	138	51	42	116	276	102
Fitting and valves	7	1	1	0	232	36	7	0	1624	252
Manifold, reversing 6"	2	4	5	0	210	36	170	0	420	72
Mooring, barge	1	34	78	348	435	261	78	348	435	261
Pipe & acc., API, 6" 1 mi.	0.5	48	50	58	754	420	25	29	377	210
Pipe & acc., tubing, 6" 1 mi.	5	29	52	43	464	319	260	215	2320	1595
Pipeline, submarine, 6", 1000'	1	20	25	1378	174	2828	25	1378	174	2828
Pump fuel supply, 4 unit	3	1	1	12	75	29	3	36	225	87
Security Fence	3.5	6	7	70	322	325	25	245	1127	1138
Tank set, 4x10,000 gal	1	8	18	7	73	36	18	7	73	36
Tank, collapsible 100K	6	10	29	36	100	36	174	216	600	216
Tank, storage 4" line, 500 bbl.	3	6	12	65	261	108	36	195	783	324
Vehicle gate for fence	8	2	2	12	174	70	16	96	1392	560
				Barge Installation Total			879	2881	9826	7681

			Individual Facilities					Installation Total		
Rail Loading Facilities	Quantity	Weight	Shipping	Labor Requirements			Shipping	Labor Requirements		
10-station			Weight	Horiz	Vert	Unskilled	Weight	Horiz	Vert	Unskilled
		ston	meas. ton	man-hours by category			meas. ton	man-hours by category		
Flood pump & manifold, 1355 BPH	1	10	13	29	406	116	13	29	406	116
Headquarters Building 20j' x 40'	1	58	153	32	457	170	153	32	457	170
Loading Pump & manifold, 2500 BPH	4	14	31	22	159	85	124	88	636	340
Loading station, tank car, 10-sta	1	249	260	986	3016	6612	260	986	3016	6612
Manifold, distribution, tank car loading	1	2	2	7	65	15	2	7	65	15
Pipe & acc., API, 8", 1000'	0.5	14	16	14	290	204	8	7	145	102
Pipe & acc., tubing, 4", 1 mi	1	7	5	7	131	80	5	7	131	80
Pipe & acc., tubing, 8", 1 mi	8	36	87	58	690	464	696	464	5520	3712
Pump fuel supply, 2 unit	3	1	1	7	51	29	3	21	153	87
Security Fence	2.7	6	7	70	322	325	19	189	869	878
Tank, 4" line, 1,000 bbl	1	11	12	116	464	189	12	116	464	189
Tank, 4" line, 250 bbl	3	6	13	36	145	65	39	108	435	195
Tank, 8" lines, 3000 bbl	8	13	19	130	450	319	152	1040	3600	2552
Vehicle gate for fence	2	2	2	11	174	69	4	22	348	138
				Rail Installation Total			1490	3116	16245	15186

Tank Truck Loading Installation			Individual Facilities					Installation Total		
Installation QE 1019	Quantity	Weight	Shipping	Labor Requirements			Shipping	Labor Requirements		
3 each, 2 station facilities			Weight	Horiz	Vert	Unskilled	Weight	Horiz	Vert	Unskilled
		ston	meas. ton	man-hours by category			meas. ton	man-hours by category		
Flood pump & manifold, 785 BPH	3		12	10	215	55	36	30	645	165
Headquarters building, 20' x 40'	1	[illegible]	153	32	457	170	153	32	457	170
Loading Pump & manifold, 1400 BPH	12	9	18	10	85	25	216	120	1020	300
Loading stand, tank truck 2 station	3	10	10	218	471	1530	30	654	1413	4590
Manifold, distribution, truck loading	3	1	1	7	65	15	3	21	195	45
Pipe & acc., API, 6", 1000'	6	9	13	5	115	70	78	30	690	420
Pipe & acc., tubing, 4", 1 mi	3	12	23	20	200	160	69	60	600	480
Pipe & acc., tubing, 6", 1 mi	24	29	52	30	320	220	1248	720	7680	5280
Pump fuel supply, 2 unit	9	1	1	5	35	20	9	45	315	180
Security Fence, 1000'	8.1	16	19	188	869	877	153.9	1522.8	7038.9	7103.7
Tank, 4" line, 1,000 bbl	3	12	13	80	320	130	39	240	960	390
Tank, 4" line, 250 bbl	9	6	13	25	100	45	117	225	900	405
Tank, 6" lines, 3000 bbl	24	19	32	90	310	210	768	2160	7440	5040
Vehicle gate for fence	3	4	4	23	348	139	12	69	1044	417
				Tank Truck Installation Total			2034.9	3474.8	21014	19123.7